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No. 22.

REPORT

ON

THE NORTH SEA CANAL OF HOLLAND;

AND ON

THE IMPROVEMENT OF NAVIGATION

FROM

ROTTERDAM TO THE SEA;

TO THE

CHIEF OF ENGINEERS, UNITED STATES ARMY,

BY

BREVET MAJOR GENERAL J. G. BARNARD,
COLONEL, CORPS OF ENGINEERS, U. S. ARMY.

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Having been engaged, with the sanction of the War Department, during the past summer in examining personally, on behalf of the Tehuantepec Railway and Canal Company, some of the principal artificial waterways of Europe, I have, under the authorization of the Chief of Engineers, prepared for the information of the Engineer Department the following account of the remarkable works of modern engineering presented by the North Sea Canal and the navigation improvement from the port of Rotterdam to the sea. It is due to Mr. Simon Stevens, president of the company just mentioned, at whose expense my investigations were made, and documents and drawings procured, to state that this disposition of them is made with his cordial approval.

J. G. BARNARD,

Colonel of Engineers, and Bvt. Maj. Gen. U. S. A.

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THE NORTH SEA CANAL OF HOLLAND.

"Even among the gigantic engineering works of the present age, prolific as it is, those of the North Sea Ship Canal will take high rank, not only from their extent and difficulty of execution, but from the important results that will eventually accrue to Amsterdam as a port and Holland as a country. That great trade which, in the sixteenth century, placed Amsterdam at the head of the commercial cities of Europe, gradually declined, partly from the rise of other ports, but principally from the difficulties of navigation caused by the silting up of the Zuyder-Zee, and, above all, the Pampus Bar. Large vessels were obliged to discharge their cargoes outside, and were then floated over the bar by means of camels, which, when the water was pumped out of them, raised the vessel with them. To remedy this the North Holland Canal was cut from Buiksluyt, opposite Amsterdam, to the Helder, a distance of 51 miles, and this has been extensively used by vessels of large burden seeking the North Sea. Throughout its length it is 124 feet broad at the surface, and 31 feet at the bottom, and is available for vessels drawing 18 feet of water. The open sea can be reached in a time varying from eighteen hours to two days. But in winter even this great highway is blocked up by ice, and a large outlay has to be incurred in keeping it clear. Speculators and engineers cast longing looks on the narrow land and shallow water between the Zuyder and the North Seas—the latter from the obvious capabilities of such a route (by which 36 miles would be saved); the former, because they saw not only a direct outlet for Amsterdam trade, but a still greater inducement in the land that would arise on each side from out of the waste of water of the Wijker-Meer and the Ij."

The foregoing extract from "Engineering," August 6, 1869, sets forth briefly the characteristics and purposes of the North Sea Canal.

The allusion to the "great trade which, in the sixteenth century, placed Amsterdam at the head of commercial cities in Europe," carries the mind

back to an age of comparative infancy in the art of navigation. The fact that Amsterdam was almost an inland city, accessible from the ocean only by tedious navigation through a shallow inland sea, was not wholly disadvantageous at an era when "the use of the compass was not general, and vessels sailed slowly and tediously along the coast; when the sea voyage from the Mediterranean (whence, subsequent to the Crusades, came the rich fabrics of the East) to the winter-frozen ports of the Baltic, too long to be accomplished in one season, rendered an intermediate winter rendezvous welcome. Such rendezvous were furnished by the sea-ports of the Netherlands, which, communicating with the interior of Europe by navigable streams, appeared to be expressly created for centres of commerce and gathering points for all nations." (Schiller. "Revolt of the Netherlands").

With the increase in the size and draught of ships—the perfecting of the art of navigation, by which celerity of access and egress are rendered of paramount importance for a commercial port—and with other changes brought about by time, the peculiarity of local situation just mentioned could not fail to operate to the disadvantage of Amsterdam. What efforts have been made to obviate these disadvantages, to supply by man's energy what nature has withheld, are briefly epitomized in the passage first quoted.

Even before the making of the North Holland Canal (from Amsterdam to the Helder) it had been proposed by the reigning monarch, William I, to connect Amsterdam directly with the North Sea.* Subsequently, when experience had proved existing works to be inadequate, and the competition of other ports necessitated decisive measures, the idea was revived. The first impulse to a practical consideration of the subject was given by the common council of Amsterdam, by the appointing of a committee, which made a very important report on this question in 1852. This commission proposed, for the execution of its project, a term of fifteen years. For this reason, principally, the report was not received with favor.

In 1854 the city of Amsterdam, in connection with an unknown member of the Royal Institute of Engineers, announced a premium of 2,000

* What follows, as far as page 34, is translated and condensed from a paper read before the Royal Institute of Engineers (of Holland) by J. Dirks, resident engineer of the North Sea Canal.

florins for the project of a North Sea canal which would fulfill all the requirements, and especially that concerning the time of construction.

The prize was not awarded to any one of the ten projects which were sent for competition, though it was admitted that some of them were meritorious.

Already in 1852, before the project of the municipal commission was published, the English engineers, B. W. Croker and Charles Burn, then charged with the technical direction of the construction of drainage in Amsterdam, had projected a plan, in connection with Mr. J. G. Jäger, by which the work might be rendered a financially successful industrial enterprise, and thus give rise to the foundation of a private company for its execution.

On the 17th of April, 1853, the project was presented to the minister, Thorbecke, who expressed himself very favorably, referring it to Messrs. Van der Kun and Storm Buijsing, both now deceased.

These gentlemen, as eminent in their social position as in their reputation and capacity as engineers, after a full study of the project, a discussion of objections and the methods of obviating them, reported not unfavorably.

But it was yet necessary to hear the interested communities and water companies, so keenly interested in Holland in every question which affects the drainage system or the securities against the inroads of the sea; and thus the consideration of the plan was protracted so long that Messrs. Croker and Burn, its authors, exclaimed, in 1859, on the appointment of a tenth commission:

"Many have thought that during the last seven years the affair and all the different points had been examined so thoroughly, and by so many different commissions, that nothing could be left to be reported upon.

"Upon our projects not less than nine different commissions have reported during the last six years. Seven technically, two concerning the conditions of concession. The last appointed commission is the tenth."

The form of the North Sea Harbor, projected by Messrs. Croker and Burn, corresponds very nearly with that afterward chosen, though enclosing less area.

The embankment of the Ij in this project followed the direction of Buitenhuizen, Hof-Ambacht, Ruigoord, and Halfweg.

The southern part of the Ij would be drained. On the east side of Buitenhuizen the direction of the canal corresponded with the present one, but this section was totally exposed to the action of the tidal fluctuations of the Zuyder-Zee, and the projected sluices near Nauerna, Westzaan, and Oostzaan, would hardly have checked the expected alluvion.

In the mean time the projected canal became more and more popular, and the moment approached when the pen could be laid aside and the spade taken in hand.

Memorials were presented to the King. The common council of Amsterdam appointed a committee to promote "the canalization of Holland at its narrowest part" (*i. e.* from the Wijker-Meer, or easternmost part of the Ij, to the North Sea).

About the same time (April, 1859), the minister, Van Tets, appointed a board of the water department (Waterstaat), consisting of Messrs. Conrad, Storm Buijsing, Van Gendt, Beijerinck, Ortt van Schonauwen, Haijward, and Van Diesen.

The project of 1852 was substantially adopted. A project of a law authorizing the execution, prepared by the ministers, Van Tets and Van Bosk, was withdrawn by their successors to be followed by new projects, which also remained incomplete. Evidently there was a consciousness that the requirements of the case were not yet fully met.

Notwithstanding these manifold discussions and reports, the idea which really became the key of the present undertaking had not yet been put in the foreground, viz, the exclusion of the water of the Zuyder-Zee from the Ij (and of course from the canal), by a dam eastward of Amsterdam.

In essays, to which prizes were awarded by the Holland Company of Sciences, the Inspector General Goudriaan, as well as the chief engineer, afterwards inspector, Mentz, had proposed in 1824—each one on a different basis—a similar embankment or dam; but when, in 1828, the Goudriaan project was undertaken, so many difficulties were encountered that the canal from Ijdoorn to the Kuil of Marken (already, in conjunction with the embankment of the Goudzee, in progress, and which was to be followed

by the embankment of the Ij between Ijdoorn and Diemerbuitenveld), was suddenly ordered to be stopped by the government.*

This action was due mainly to the vehemently urged objections to the obstruction of the navigation, through the Zuyder-Zee and Ij, to Amsterdam, which the damming of the latter strait would create. The subsequent construction of the North Holland Canal caused, in great measure, these objections to lose force.†

The municipality of Amsterdam, in 1861, expressed the desire that the pending project should be modified so as to include the draining of the Eastern Ij and the reclamation of land, while, at the same time, the Chamber of Commerce and Manufactures declared that the objections urged thereto, in 1828, under a very different state of affairs, no longer existed.

This important change of opinion led to greatly improved plans, upon which Mr. Jäger, in December, 1861, accepted the concession, ratified with some modification of details, by the law of January 24, 1863.

After the foregoing sketch of the history of the origin of this great undertaking, I proceed to give some descriptive particulars of the work itself, commencing with the harbor on the North Sea. (See Plate I.)

This harbor was planned by the eminent English engineer Mr. John Hawkshaw, of London, (consulting engineer of the canal company), and the actual construction involves no other deviation from his design than a slight change in the direction of the axis of the harbor entrance. The width of this entrance is 260 metres.

The two piers are to be extended to the depth of 8 metres below the level of low water, corresponding with about 9.50 metres below daily high water and 8.50 metres below A. P.‡

The roots of these piers, at the foot of the downs on the beach, are

* This work (intended to avoid the Pampus Bar by a canal between the points mentioned), crossing the Goudzee and having its outlet at the eastern end of the island of Marken, is delineated upon the government charts of Holland (No. 25). For its day, it scarcely falls behind the present North Sea Canal in boldness of design, involving, as it did, the damming of the Ij and the enclosure of the Goudzee.—J. G. B.

† For the *coast* trade of the Zuyder-Zee to Amsterdam, and in fact for sea-going vessels of considerable magnitude, the spacious locks of the Ij dam now under construction afford ample facilities of passage.—J. G. B.

‡ A. P., Amsterdam Peil, ("Peil" signifying "gauge," or "sounding.") The fixed plane of reference for all surface or water levels in Holland, and even in contiguous territories.—J. G. B.

1,200 metres distant one from another. Their directions converge, so as to make an angle of about 77° with their base line.

At 1,200 metres from their origin, the piers, distant 660 metres from one another, commence to converge more rapidly, so that, with an increment of length of 345 metres (1,545 in all), they terminate 260 metres apart at the harbor mouth.

To obtain the requisite depth the area between these piers is to be dredged to an elliptic form for a width of 650 metres, and to a depth of $8^{m}.50$ below A. P. at the entrance, $7^{m}.50$ on the land side, the *harbor* area being 55 hectares; while the total area enclosed by the piers is fully 100 hectares.

Stevenson, in his work on the "Design and Construction of Harbors," gives the following, partly empiric, expression for the co-efficient of reduction of waves in the interior of harbors:

$$\frac{x}{H} = \sqrt{\frac{b}{B}} - \frac{1}{50}\left(1 + \sqrt{\frac{b}{B}}\right)\sqrt[4]{D}$$

H = height in feet of waves outside.
x = reduced height at place of observation in the interior of harbors.
b = width of entrance, or of harbor's mouth.
B = width of harbor at place of observation—all in English feet; and
$\frac{x}{H}$ is the "reductive power" of the harbor, or its co-efficient of reduction.*

Observations made at Sunderland, Kingstown, Macduff, Fisherow, and Buckie have proved the utility of this formula, and that the actual reduction is usually even more than indicated by it. Hence in the North Sea Harbor, at 600 metres (1,970 feet), within the mouth, where the width is 850 metres (2,800 feet), the waves will be reduced to 0.35 of their height at sea.

The construction of the piers follows mainly the system adopted in England for the Admiralty's pier at Dover and the foundations of the forts ("Horse Sand" and Spit Bank Forts) of Spithead,† and of the Breakwater Fort at Plymouth.

* See 8th ed. of Encyc. Britta.; also "The Civil Engineer and Architect's Journal," 1857, p. 9. In the above it is assumed that the piers are high enough to screen the inner area, if large, from the wind, the depth uniform, the width of entrance not very great compared with the width of the wave—the walls vertical and the distance, D, in feet, from the harbor-mouth to the point of observation, not less than 50 feet.—J. G. B.

† See Professional Papers of the Corps of Engineers, U. S. A., No. 21, p. 21, for description of these foundations. They were put down under the direction of Mr. Hawkshaw.—J. G. B.

These works consist of a solid sea-wall, built with an inclination of ½ of the height and resting on the natural bottom, without any protection whatever along the foot.

Wherever, as in the case of the constructions just cited, the firm rock can be found at a trifling depth below the ground, and a dredging away of merely a thin layer of mud is required, this system is entirely satisfactory.

Another system is resorted to in England at places where the bottom is neither rock nor material firm enough to resist the abrasion of waves and currents.

A broad base is first formed of stone fragments thrown in "*à pierre perdue*" ("riprap," as termed in America). On this, after it has been made level, the piers are constructed as before, presenting, when finished, the same appearance as the works first mentioned.*

The construction of the piers for the North Sea Harbor was commenced on the Dover plan, the same contractors, Messrs. Henry Lee & Son, who have so successfully executed the magnificent pier at that port, having taken the contract for the entire work of the North Sea Canal, naturally had recourse to a method with which they were familiar.

It soon became apparent that for the treacherous sands of the Netherlands coast some modifications must be made. It was found impossible to get a firm bed for the concrete blocks; and, if accomplished, the first storm swept away the sand from underneath, causing the superincumbent structure to give way. Thus, in December, 1867, the then finished portion of the northern pier was seriously damaged.

The first remedial experiment was, after placing the first layer of concrete blocks on the bottom, to allow them to remain till they had become well embedded in the sand; then, by the hand of divers, to cut this layer to a level, to serve as a foundation for the upper courses.

* The harbor of Holyhead, under charge of the same eminent engineer who planned the North Sea Harbor, differs from the works just described in consequence, rather, of the abundance of stone suitable for "riprap" which the contiguous mountains afford. The stone is obtained by blasting with charges of, sometimes, 10 tons of powder. The rock thus obtained is thrown in along the line of the breakwater, leaving to the action of the waves the reduction of the mass to suitable shape. On the middle of the mound thus formed and shaped, a massive stone wall, with vertical sides, is built. This plan is that finally adopted, I believe, at Cherbourg; it having been found impracticable to maintain the "riprap" above the plane of low water; that is, above the inferior limit of exposure to violent wave action.—J. G. B.

This answered better, but the work could not be executed speedily enough, even though the excessive expense were disregarded.

The plan was then tried of making a (riprap) foundation of basaltic blocks. At first marginal blocks of concrete were laid outside the foot of the pier profile to retain or bound the sides of this mass, but this method gave way to an extension of the basalt with natural side slopes.

This last system (Pl. II) is now finally adopted. The layer of basalt, one metre or more thick, covers a breadth exceeding that of the pier by about 10 metres on each side, and is heaped up against and almost to the height of the lower layer of concrete blocks.* This method of construction occupies a middle term between that applied to the Dover pier and that described for the breakwater at dikes of Portland and Holyhead.

A different method was followed in connecting a part of the northern pier with the mainland. This part was commenced *in* the sea, in the execution of an unsuccessful experiment to carry on the work from thence in the *direction of the surf*—(*i. e.* landward.) This surf is much heavier than on the English coast, and embarrasses very much the construction of the beach ends of the piers.

So much *scour* took place between the isolated portion of the pier and the shore, that that construction would, perhaps, itself have been carried away had not the gap shoreward been promptly filled up, regardless of expense, with concrete blocks, "*à pierre perdue*," carried up to low-water mark. This latter method of construction would, for the whole work, have been, in reference to the contracted sum, a financial impossibility.

The mobility of the sand made, too, the preservation of the wooden scaffolding (bearing a railway on top) very difficult. This rested on screw-piles, inserted in the sand on both sides of the piers. In stormy weather the sand was swept away and the piles deprived of support, making necessary frequent renewals of the scaffolding. Lengthening pieces of cast-iron were

* The basaltic blocks are loaded on cars which are run out to near the end of the constructed pier and discharged. From the pier the stone is taken on scows which are moved out, in advance of the pier construction, and their contents thrown upon the bottom. The scour of waves and currents is found to make the bottom near the end of the pier considerably lower than the natural bottom. Hence the riprap fills up the excavation and scarcely rises above the bottom.

Basalt from the Rhine is, in Holland, the cheapest and most easily attainable stone for such purposes.—J. G. B.

added to the piles that they might be screwed deeper into the soil, without real benefit, however, for, by the storms of the autumn of 1869, the whole scaffolding was carried away.

The agent for the harbor works of the contractors, Mr. Darnton Hutton, then designed for each pier a movable apparatus (derrick), which is moved along the top of the finished work, and projects its arm about 12 metres beyond the extremity.

The concrete blocks, which are let down from this projecting arm during one week,* support, in their turn, the heavy weight of the apparatus during the next week.

Although one of the movable scaffolds (called "Titans") was precipitated from the northern pier by the storms of October, 1870, this accident has caused, in the new machine immediately constructed, only slight alteration. The new northern "Titan" has been arranged with some improvements in the details, the most important of which is the adapting to it of a turning steam-crane.

This modified arrangement, as well as the original "Titan" on the southern pier, are now exclusively in use.

The concrete blocks, out of which the piers are constructed, consist of one measure of Portland cement, four measures of gravel (for the outside blocks), or broken bricks (for the inside blocks), and five measures of sand.†

Considering, however, that 1.35 cubic metres of dry materials are required to prepare 1 cubic metre of concrete, the volume of the finished blocks contains really, instead of $\frac{1}{10}$, $\frac{1}{7}$ to $\frac{1}{8}$ of Portland cement.

Every cargo of cement is examined carefully. The specifications contain, in relation thereto, the following stipulations:

The cement must be formed in small blocks of proper form, which, after forty hours, must resist a tension of 7.9 kilograms per square centimetre, and, after sixty hours, a tension of 10.3 kilograms per square centimetre.

Immerged, they must, moreover, after seven days, resist a tension of 14 kilograms per square centimetre.

* These blocks are transported along the top of the pier and brought within reach of the derrick arm by rail cars.—J. G. B.

† The specifications state *four* measures of sand to *five* of gravel or broken bricks. (See App. II.)—J. G. B.

Besides this, bars and cakes must be made of the cement. After having been immerged twenty-four hours, they must show neither marks of cracks, nor softness on the surface.

The preparation of the concrete for blocks takes place in iron cylinders, which are revolved by a steam-engine during some minutes around diagonally transverse axes. They are charged with a cubic metre of dry material, to which, for the outside blocks about 165, and for the inside blocks about 200 litres of water are added. The capacity of the cylinders is 1.65 cubic metre.

From these the mixed concrete goes into the forms, where it hardens in a few days sufficiently to be lifted as a solid block by means of iron tongs.

According to the specifications the blocks must be, in the summer at least two months, and in the winter at least three months old, before use in the piers above low water. Below low water it is only allowed to use blocks more than four months old.

The height of the concrete blocks is 1.067 metres (3½ English feet); the breadth, 1.219 metres (4 English feet).

The length of the blocks varies—in order to get the required connection—from 1.524 metres (5 feet) to 2.743 metres (9 feet); recently, however, blocks have been constructed even of 3.962 metres (13 feet) length. These heaviest blocks have a content of more than 5 cubic metres, the smallest of 1.982 cubic metres.

In general terms the dimensions of the outer blocks have gone on increasing, as appears from the fact that the average contents of every constructed outer block was—

In 1866 (615 pieces), 2,395 cubic metres.
In 1867 (4,751 pieces), 2,329 cubic metres.
In 1868 (1,907 pieces), 2,243 cubic metres.
In 1869 (5,209 pieces), 2,377 cubic metres.
In 1870 (4,706 pieces), 2,792 cubic metres.
First four months of 1871 (535 pieces), 3,125 cubic metres.

The average contents of every constructed inner block was—

In 1866 (2,352 pieces), 3,213 cubic metres.
In 1867 (5,112 pieces), 3,011 cubic metres.
In 1868 (1,078 pieces), 3,044 cubic metres.
In 1869 (2,489 pieces), 3,160 cubic metres.
In 1870 (2,338 pieces), 3,044 cubic metres.
First four months of 1871 (505 pieces), 3,061 cubic metres.

The specific gravity of the outer blocks is more than 2.00; that of the inner blocks, 1.73 *a* 1.80. The weight, therefore, of one of the largest blocks is about 10 tons; that of the smallest, very near to 4 tons.

Notwithstanding these weights, loose blocks have been repeatedly swept away from the piers, and sometimes damage has been caused to the exposed sea ends of the work.

This explains the increasing weight of the outer blocks, which, by their "*vis inertia*" alone (when thus exposed), must keep the piers together.

Recently blocks have been *doubled* by connecting two with strong cement-mortar with good success, these joints becoming stronger than the block itself.

Another measure of security employed during the last year has been the insertion of anchor-ties of 5 centimetres (2 inches) square, inserted in different directions through the layers.

Below low-water the blocks, suspended from the arm of the derrick, are laid with great care by helmet-divers, who are under water many hours of the day. No mortar is used, but the joints are well fitted and the beds well levelled.

From low-water the blocks are laid in cement. For the lowest joints, which are only a few hours above water, quick-hardening Medina cement, of the Isle of Wight, is used; for the higher joints, Portland cement.

The progress of the work is, naturally, not distributed proportionally over the whole year, as appears from the subjoined compilation of the lengths constructed, taken per half year:

	North pier.		South pier.		Total.
	First half year.	Second half year.	First half year.	Second half year.	
Length built before 1868	152m.		.....	.....	152m.0
Length built, 1868	39m.8	105m.9	.....	.....	145m.7
Length built, 1869	134m.3	54m.4	.....	127m.0	315m.7
Length built, 1870	67m.9	39m.4	176m	102m.2	385m.9
	242m.0	199m.7	176m	229m.2	998m.9
1868–1870	441m.7		405m.2		
1871, (till May 20)	58m.0		72m.0		130m.0
Length, May 20, 1871	651m.7		477m.2		1,128m.9

If ever the proverb "All beginnings are difficult," has found verification, it is certainly here in the execution of this work on the shallow and shifting coast of Holland.

But the yearly figures are progressive, and the experience already obtained has nearly surmounted the difficulties which so seriously obstructed the early progress.

The dimensions of the piers in the cross profile are as follows (Pl. II):

$6^m.10$ for the first 580 metres length on the land end.
$6^m.82$ for the following 340 metres length.
$7^m.12$ for the following 275 metres length.
$8^m.20$ for the last 350 metres length.
The diameter of the pier-heads is $11^m.10$.
The height of the piers above A. P. is as follows:
Top of the parapet of the pier-heads, $5^m.10$.
Top of the pier-heads at the foot of the parapet, $3^m.90$.
Top of the parapet of the piers, $4^m.10$.
Top of the piers at the foot of the last-mentioned parapet, $2^m.90$.
Inner top line, $2^m.75$.
Top breadth of the parapet, $1^m.50$.
Inclination of the sides of the piers, $\frac{1}{7}$ of the height.

The parapet consists entirely of concrete, moulded on the spot in previously placed forms.

Behind the parapet is a pavement of bricks in cement, supported by a band of granite along the inner top line.

In the beginning of May, 1871, 15,163 concrete blocks, of a total volume of 40,827 cubic metres, were worked up in the two piers.

The basalt and other natural stone supplied amounted to more than 29,000 cubic metres, of which about 23,000 cubic metres had been worked up.

The basalt foundations had made progress on the 20th of May—

At the northerly pier to 924 metres outside of the foot of the downs, or 272 metres outside the work constructed above water.

At the southerly pier to 970 metres outside the downs, or 493 metres farther than the constructed work.

The construction of the piers there has caused a considerable accumulation of sand and local enlarging of the beach, as is clearly visible on the ground.

DESCRIPTION OF THE CANAL.

The axis (Pl. I) of the *North Sea Canal* intersects the foot of the downs on the beach about 500 metres south of shore-pile 55.*

Eastward, it runs at first in the direction of an arc of a circle, with the concave side turned southward, forming along a length of 1,206 metres the western half of a segment with a chord of 2,400 metres and a versed sine of 100 metres, corresponding to a radius of 7,250 metres.

Touching the arc, which serves principally to protect the North Sea locks (now in course of construction at its eastern end) against the action of the waves, the axis runs in a straight line eastward, over a length of 3,694 metres, till near the high road on the north side of Velsen.

Then follows an arc of a circle of 1,640 metres length and 2,240 metres radius, with the concave side turned southward.

Then a straight line of a length of 3,600 metres.

After this an arc of a circle of 1,040 metres length and 2,000 metres radius, with the concave side turned northward.

Then a straight line of 8,250 metres length.

Then an arc of a circle of 1,350 metres length and 4,000 metres radius.

Then an arc of a circle of 600 metres length and 2,425 metres radius, both with the concave side turned southward.

Finally, a straight line, in the direction of the great channel to Amsterdam, with length of about 2,050 metres.

The entire length, from the foot of the downs to the "*diep*" near Amsterdam amounts, accordingly, to 23,700 metres.

It will be seen, in the above, that the curves of the canal will obstruct the navigation very little and oppose no obstacle to the construction of a railroad along the tow-path.

There are two sections, or portions, of the canal located upon the land; one from the North Sea to the Wijkermeer† at Velsen, 5,980 metres long; the other across the peninsula of Buitzenhuizen, 800 metres long.

* The coast-line of Holland is marked by beach-marks, or stakes, distant 1,000 metres from each other, and numbered.—J. G. B.

† The "Wijkermeer" is the extremity, or extension, of the Ij between Velsen and the peninsula of Buitzenhuizen. Thence to Amsterdam the Ij (pronounced as the English letter I) is distinguished as the Westelijk Ij, from the portion lying between Amsterdam and the Zuyder-Zee.—J. G. B.

The portion of the canal located in the Wijkermeer has a length of 4,370 metres.

That lying in the Western Ij has a length of 12,550 metres.

The cross profile of the North Sea Canal is twofold.

On the mainland the depth is 7.50 metres below A. P.; width at bottom, 27 metres; slopes of 2 base to 1 rise, ascending to 1 metre below A. P.

Then, on both sides, a horizontal blind berm of 2.50 metres.

Then, again, a slope of 2 base to 1 rise to 0.50 metres below A. P.

Then, on both sides, a second horizontal berm of 1.50 metres.

Finally, slopes of 2 base to 1 rise, ascending to the local height of the tow-paths or parallel roads, which will have a width on the south side of 10, and on the north side of 5 metres.

In the Wijkermeer and the Western Ij, the depth and bottom width are the same; thence slopes of 2 base to 1 rise ascend to the surface of the sea bottom, and thence blind berms, on both sides, extend over the local bottom to a width of 30 metres.*

Slopes of 4 base to 1 rise then ascend from the inner border of the said berms to 1 metre above A. P.

The lateral dikes have a width at top of 5 metres, and a landward slope descending with 4 base to 1 rise to the drainage "polders," which will be created on each side of the canal.

From this description it follows, that the breadth of the excavation on the level *at the height of A. P.*, is 65 metres.

The breadth at A. P. of the canal sections in the Wijkermeer and the Western Ij is much larger. It also depends upon the local bottom heights and is, for instance, at an Ij bottom of 1 metre below A. P., 121 metres; and at an Ij bottom of 3 metres below A. P., 129 metres.

From a point 21,000 metres on the east side of the downs to the end of the canal, the bottom width increases gradually from 27 to 50 metres, which last width joins the "*diep*" near Amsterdam.

The dikes then turn away from the canals, the northerly one running

* These wide blind berms, when the canal surface is reduced to $0^{m}.50$ below A. P., will have but three or four feet of water on them, and will serve to protect the lateral dikes from wave abrasion. They will probably be overgrown by aquatic plants.—J. G. B.

in a straight line to the Buikslooterham—the southerly one in a curved line to Amsterdam.

To connect the different navigation and drainage sluices along the border of the Ij and the North Sea Canal, the following *side canals* between the different drainages will be reserved, and dredged to the following breadths and depths:

Side canal A, toward the entrance of the outer harbor of Beverwijk: bottom width, 10 metres; depth, 2.50 metres below A. P.; length, about	950 metres.
Side canal B, through the Wijkermeer toward Spaarndam: bottom width, 22 metres; depth, 4 metres below A. P.; length, about	3,900 metres.
Side canal C, through the Western Ij (along Buitenhuizen) toward Spaarndam: bottom width, 25 metres; depth, 4 metres; length, about	3,700 metres.
Side canal D, toward Nauerna: bottom width and depth same as side canal C; length, about	1,100 metres.
Side canal E, toward Westzaan: bottom width, 15 metres; depth, 3 metres; length, about	500 metres.
Side canal F, toward Halfweg: bottom width, 24 metres; depth, 4 metres; length, about	4,950 metres.
Side canal G, increasing the depth of the Voorzaan: bottom width, 30 metres; depth, 5 metres; length	1,100 metres.
Side canal H, toward the mill-sluices of the Barndegat: bottom width, 10 metres; depth, 2.25 metres; length, about	1,750 metres.
Side canal I, toward Oostzaan: bottom width, 10 metres; depth, 3 metres; length, about	3,050 metres.
Total length of side canals west of Amsterdam, about	21,000 metres.
Add to this, east of Amsterdam, a side canal toward Nieuwendam, at a depth of 3.50 metres below A. P., with a bottom width of 10 metres, length about	600 metres.
While the main canal (as above) has a length of about	23,700 metres.
Total length of all canals about	45,300 metres.

With the exception of the differences in depth and bottom width, the cross profiles of the side canals correspond with that of the main canal in the Wijkermeer and the Western Ij.

The blind berms, however, are 10 metres narrower, and hence only 20 metres wide.

With regard to the *displacement of earth* required for the total execution of the work, the following summary is given:

The trench between the foot of the downs on the shore and the Wijkermeer has, in each one of the sub-mentioned cross profiles, the therein-named average depth in metres:

	Distances from the foot of the downs—					
	0m.	1,000m.	2,000m.	3,000m.	4,000m.	5,000m.
0m.	12.5	15.9	15.4	13.9	11.4	8.3
100m.	13.5	15.9	15.5	14.0	11.4	8.0
200m.	12.9	15.4	15.5	13.5	11.2	7.9
300m.	13.5	15.4	15.8	13.4	10.9	7.8
400m.	13.6	15.7	15.5	12.8	10.9	7.8
500m.	14.7	16.2	15.9	12.4	9.8	7.8
600m.	14.9	15.5	18.4	11.9	9.8	7.7
700m.	16.1	15.6	15.0	11 2	9.4	7.7
800m.	15.8	15.8	14.5	10.9	9.4	7.8
900m.	16.8	15.4	13.9	11.4	8.8	7.9

Subtracting from each one of these numbers 7.50 metres, or the depth below A. P., the reference figures for a correct profile of the *narrowest part of Holland* will be obtained. ("Holland op zijn Smalst").

The excavation at Velsen amounts to	4,710,000 cubic metres.
The main canal in the Wijkermeer about	1,207,000 cubic metres.
Buitenhuizen	257,000 cubic metres.
The main canals in the Western Ij about	2,516,000 cubic metres.
	8,690,000 cubic metres.
Add to this for the North Sea Harbor, according to the original soundings, and hence without allowance for alluvion or deepening, about	1,220,000 cubic metres.
And for the side canals about	1,335,000 cubic metres.
Total digging or dredging about	11,245,000 cubic metres.

Of this quantity there has been dug or dredged in cubic metres:

	Velsen, on the east side of the foot of the downs.	Buitenhuizen.	Wijkermeer and Western Ij.	Total.
1865	592,152	.....	15,200	607,352
1866	980,486	80,094	60,732	1,121,312
1867	606,253	67,887	359,710	1,033,850
1868	166,577	25,097	496,046	637,526
1869	253,309	40,798	446,078	740,185
1870	503,164	11,119	580,226	1,094,509
1871, (first four months)	107,538	2,630	56,823	166,991
Totals	3,209,479	177,431	2,014,815	5,401,725

Of the excavations at Velsen, 1,798,835 cubic metres have been transported to the margins, and 1,410,644 cubic metres to the Wijkermeer or the Western Ij, and used in raising the lateral canal-dikes in those waters.

At the *dredgings* in the Wijkermeer and the Western Ij, steam-dredges are used with self-working discharging apparatus, by aid of which the advantage is gained that the dredging can be continued uninterruptedly day and night; that no vessels or men are wanted for the transportation of the mud, and that the working is not materially affected by the wind, which, on an extended surface of water, might impede the movements of scows.

The discharging apparatus is quite simple. (See Pl. III, and also App. I). The mud is emptied into a vertical cylinder, which is fixed to the steam-dredge. On the lower end of this cylinder works a horizontal centrifugal wheel, of more than 1 metre diameter. This wheel is put in motion by the steam-engine of the dredging machine. It makes about two hundred and thirty revolutions per minute, and forces the mud, received by the cylinder, into the floating tube. At the same time the mud is mixed with water, drawn up *from below* by the revolution, so that the mixture in the floating tube consists of 40 to 50 per cent. of solid matter (mud, clay, and sand), of 50 to 60 per cent. of water.

The floating tubes consist of wooden tubes of about 15 metres length and 0.40 metre diameter, joined together by flexible connections of leather (wrapped with band-iron). These floating tubes float zigzag-wise on the

surface of the water for distances of 250 metres or more. The end is brought through, or even over, the previously made sand deposits, and behind these sand-dikes a jet of muddy water is discharged. The solid portions settle and are deposited over a considerable surface.

The four steam-dredges in use at the dredging works in the Wijkermeer and Western Ij consist of two small ones (each about 12 horse-power nominal), constructed, without discharging apparatus, by Messrs. Tilkin Père & Co., La Boverie, near Liege, and of two larger ones constructed by Messrs. William Symons & Co., London works, at Renfrew on the Clyde.

Of the larger dredges a short description, with illustrations, can be found in the English periodical "Engineering," Vol. II, 1866, pp. 182 and 183.

To enable a judgment to be formed of the work performed by the four steam-dredges near the North Sea Canal, it may be said that from April 1, 1868, till October 31, 1869, inclusive, the four boats may be considered to have worked jointly *fourteen months, day and night.* During this time, according to the soundings made in the profile, 804,000 cubic metres of clay and sand have been dredged, or averaging per month by one boat, $\frac{804,000}{56} = 14,357$ cubic metres; in a day—calculating the month at twenty-five working days—574 cubic metres; and in an hour—considering the working day to have twenty hours—about 29 cubic metres.

These results must be considered as the averages of a large and a small dredging-boat, for separate accounts for each boat have not been kept.

These results are below the reality, owing to a considerable deposit continually going on, which is not taken account of in measurements by soundings.

Every steam-dredge, with the described arrangements—as well the great as the small ones—is equipped with ten men, who are relieved day and night; consequently, a total of twenty men for each boat.*

One of the most difficult subdivisions of the work is to construct the *canal and drainage dikes* in the Wijkermeer and the Western Ij.

* The discharging apparatus is patented in England in the name of Mr. Freeman, and in the Netherlands in the name of Mr. Burt, who has special charge of the dredging. He has introduced it successfully in the dredging of the Sulina mouth of the Danube.

Until 1868, inclusive, this had been done exclusively by the aid of locomotives.

This course of working had three disadvantages:

Firstly, the necessity of making the sand-dikes—at the same time auxiliary railroads—wide enough to contain the rails and switches (which latter were incessantly changing their position), and high enough to be always above high tide. Hence arose a profile, very much surpassing the prescription for the drainage-dikes or tow-paths on the Wijkermeer and the Western Ij.

Secondly, the necessity of constructing the dikes almost exclusively of sand from the Velsen excavations, to the exclusion of the mud dredged on the spot from the Wijkermeer and Western Ij.

Thirdly, the nearly double expense of the transports by locomotive, in comparison with tug-boats and scows.

To overcome these difficulties the contractor procured, in the last half of 1869, four steam tug-boats and seventy-two large scows; while near the high-road at Velsen, on the north and south side of the canal, permanent wharves were built, on the top of which the sand trains are pushed. The scows lying underneath them are loaded by immediate dumping from the sand cars.

Since this method of sand transport has come in regular use, the dikes are dumped up to not more than the required profile, to the great saving of material, as shown by the fact that, before 1870, 11,915 metres length of canal dike consumed 1,028,000 cubic metres of sand, or 86 cubic metres per metre length, while in 1870 and 1871 (first four months), 7,008 metres length of canal dike consumed but 382,000 cubic metres of sand; only 55 cubic metres per metre length, notwithstanding that this last length was in deeper water.

The use of dredging matter in the canal dikes has been applied since the last year, with good success, by Mr. Freeman, dumping it along gutters on the middle of the top of the previously formed, but incomplete, sand-dikes, thus raising the dikes from beneath the water surface to A. P.

In this connection an arrangement indicated by the name of *mud-carrier*, has been found of great utility. This arrangement concurs in principle with the endless canvas (*"toiles sans fin"*) used on the Suez Canal.

The gutter or dumping-trough of one of the larger steam-dredges is lengthened, and dumps the mud on the iron plates of what may be called a "plate-chain," with upright flanges.

This plate-chain is kept in motion around sheaves at each end, so as to dump the mud which falls upon the plates at one end, at a distance of 35 metres, upon the canal dikes.

The wide blind berms of the principal canal (30 metres) rendered an arrangement of this kind indispensable, in order to carry the mud from the dredges to the dikes without the use of boats.*

In order to raise the dikes *above* water afterward, just as for the first construction, sand is again required, but now mixed with clay.

The "mud-carrier" provides this supply of sand, in an efficient manner, by a steam-crane, which regularly hoists out of a scow a basin holding half a cubic metre of sand, which, at intervals of about five minutes, is dumped upon the plate-chain, and thus provides periodically a certain quantity of sand, which stiffens the mud dumping, raises it and enables it, after a few days' desiccation, to receive, with the clay covering, the required profile.

Besides the above arrangement for supplying a proportion of sand, at other places wheel planks are used, by which the workmen bring the sand directly from the scows to the margins of the future tops, while at the same time the wet mud is raised against it.

The total length of the canal dikes in the Wijkermeer and the Western Ij amounts to about 60,000 metres, on which about one-third the work was done May, 1871.

As already mentioned, the North Sea Canal will, with its branches, form an inner basin, closed against the tides of the North Sea by the locks near Velsen, and shut off from the Zuyder-Zee by a barrier dike, or dam with locks, near Schellingwoude.

The North Sea locks (Pl. IV) are situated, with the outer front, at 1,107.80, and with the inner front at 1,262.20 metres east of the foot of the downs. The length between the fronts is consequently 154.40 metres.

They consist of a large tide-lock in the middle; in the southern part a

* I am under the impression that this "mud-carrier" is found too expensive, and is now abandoned for a simple wooden trough.—J. G. B.

small tide-lock, and in the northern part an outlet sluice, both the latter near the outer front of the great lock.

This latter is divided into two sections, forming an eastern and a western lock-pond.

It has five pair of gates, of which, at the outer extremity, one pair of tide and one pair of ebb shutters; one pair of tide-shutters divides the sluice in two sections; and at the inner extremity, one pair of tide and one pair of ebb shutters.

The southern tide-lock has, at the outer end, two pair of tide and one pair of ebb shutters; and at the inner end, one pair of tide and one pair of ebb shutters.

The outlet sluice has two pair of tide and one pair of ebb shutters.

The lock-walls of the great lock extend the whole length; for the smaller southern lock an earthen slope supplies the place of the southern wall along the lock-pond.

The walls will be built exclusively of ordinary brick-work, consisting of pressed bricks, externally (where exposed to weather), and for the rest, ordinary hard-burned bricks.

The hollow quoins, mitre-sills, stairs and copings, are made of common granite.

Length of the outer lock-pond, between the points of the tide-gates	**70.00 metres.**
Length of the inner lock-pond	**50.00 metres.**
Total length of the combined lock-pond, being at the same time the distance from the points off the ebb gates	**120.00 metres.**

Small tide-lock.

Width at A. P.	**12.05 metres.**
Inclination of the walls, $\frac{1}{20}$.	
Depth on the mitre-sill	**5.00 metres below A. P.**
Length of the lock-pond, between the points of the outer and inner tide (or ebb) gates	**70.00 metres.**

Outlet sluice.

Width at A. P.	**10.05 metres.**
Inclination of the walls, $\frac{1}{20}$.	
Depth on the mitre-sill	**5.00 metres below A. P.**

The top of the lock-walls outside of the outermost gate will be at a height of 5 metres above A. P.

That of the walls between the outermost and second pair of tide-gates, at a height of 3.60 metres above A. P.

Of other parts, at a height of 2 metres above A. P.

In making the excavations for these locks, a very powerful steam-pump kept the surface of the water at a depth of 9 to 10 metres, and in partial drainages, with Archimides screws, even at a depth of 11 metres below A. P., or about 20 metres below the circumjacent downs; a depth probably never before drained in the Netherlands.

The foundation of the North Sea locks fulfils the expectations based upon carefully made borings. The formation this developed is, throughout, like the visible surface, sand. This, compressed for centuries by the overlying sand-downs 20 metres high, needed not the use of piles.

Among the embankments, of which so many have been, during centuries past, constructed in the Netherlands for protection against the rivers or the ocean tides, or for purposes of drainage, that across the Ij in course of construction between Schellingwoude and the Paardenhoek, near Zeeburg, will occupy a prominent place.

As to length, it yields only to that made for the railroad across the Eastern Scheldt, while the depth of the gap of 500 metres still open, amounted in the past winter to 8 metres, and averages 5 metres below A. P.

The length is about 1,360 metres, of which 300 metres lie on the north side, and 1,060 metres on the south side of the axis of the central tide-locks.

The cross-profile of the dike is shown in Pl. II, Fig. 2.

The portions of the slopes, more than $0^{m}.50$ below A. P., are—when they consist of fascine mattresses sunk on top of each other—brought up under inclinations not steeper than $\frac{3}{4}$ base to 1 rise on the outside, and $1\frac{1}{4}$ base to 1 rise on the inside.

The slopes, berms, and top of the dam, must be covered with a thickness of at least 1 metre of good clay.

After the closing of the dike the fascine works on the inner and outer slope are to be taken up and their place supplied by a stone slope descending

on the outer slope from the top of the dike, and on the inner slope from the height of the berm, both as far as to $0^m.50$ below A. P.

This dike is nearly completed. An opening of 250 metres, for navigation and drainage, is kept open provisionally.

For the building of the Zuyder-Zee locks an extensive coffer-dam was necessary. In December, 1865, Mr. Hawkshaw proposed for its construction the driving of two rows of piles of $0^m.30$ square, close together, the rows being spaced 2 metres one from another, each pile from 14 to 16 metres long. Suitable girders and struts connected the piles of each row, and the rows with each other. The inner diameter of this coffer-dam is 160 metres.

Mr. Hawkshaw had applied with great success a similar dam, although apparently under less favorable circumstances, for the new dock in Hull, and the building of the entrance sluice of that work.

Nevertheless the difference between high tide and ebb is, at Hull, at neap tides, 5.00, and at spring-tides, 6.30 metres, while, moreover, the storm tides in the Humber were to be guarded against.

It turned out, however, that there were in the Ij difficulties which, in the more firm soil at Hull (there likewise alluvial), had not been encountered.

The coffer-dam near Schellingwoude, finished about May, 1867, was drained in May, 1868, and the interior digging for the locks commenced. About the end of August this excavation had been very far advanced, and one hundred and eighty foundation piles driven, when a spring was discovered near the suction-pipe of the centrifugal pump. In consequence of this the coffer-dam was temporarily filled in order to guard against the serious consequences which might ensue.

The defect was repaired, the ring again drained after the lapse of a month, the pile-work resumed, and on the 25th of October, 1868, five hundred and eighty-seven foundation piles had been driven. On that day the dam began to leak in many places, owing to an unusually high tide, in consequence of which it was decided once more to let in the water. Near the northern sluice, abrasion of the inner sand dumping was then discovered, owing to which the coffer-dam, at this place, gave way.

The pile work had therefore to be stopped, but an immediate reinforcement to the dam was commenced by the driving in of a third ring inside the

other two, and the raising of outer and inner sand slopes (the outer one protected with clay and fascine work) to the whole height.

After the breach had been closed, and the third ring had been completed, long iron siphons were procured for the eventual admission of water. The new sand-dumpings being completed and partly provided with osier-work, the drainage of the ring was recommenced, and the pile-work could be resumed on the 10th of May, 1869.

At the end of October, 1869, six thousand eight hundred and twenty-nine foundation piles had been driven. At the end of this month the water of the Ij had risen against the coffer-dam as far as 1.44 metres above A. P. The stage of the water in September and October had marked, for not less than fifty-six hours, higher than $0^{m}.80$, and for fully thirty-four hours, higher than 1 metre above A. P. The northwestern part of the coffer-dam finally showed a dangerous settling, which prompted a partial filling by means of the siphons. For inner strengthening, sand-bags, wooden supports and props, were immediately applied by the vigilance of the agent of the contractors, Mr. T. C. Watson. The drainage was resumed on the 22d of November, and the driving of piles continued from the 29th.

The subsequent progress of the work was unimpeded by accidents, and in March, 1870, the pile-work for the locks was finished.

The total number of piles amounts to eight thousand eight hundred and ninety-six pieces, delivered at an average length of 14.40 metres (128,260 metres in total), and driven an average depth of 13.50 metres (119,813 metres in total).

The foundation was ready in the month of April, 1870. It contains 2,667 cubic metres fir timber and 33 cubic metres oak timber, besides 1,819 cubic metres concrete.

On the 29th of April, 1870, the memorial stone was laid by His Majesty the King, and upon this occasion the name of *Oranje sluizen* (Orange locks) was given. These locks are now entirely finished.

The construction and the principal dimensions of the Zuyder-Zee (now Orange locks) are as follows. (Pls. V and VI.)

They consist of three tide-locks, with an outlet sluice at the south side and three drainage sluices at the north side.

The three tide-locks are divided each in two sections, forming three eastern and three western lock-ponds.

Each tide-lock contains five pair of gates, of which, at the outer end, one pair of tide and one pair of ebb gates; then one pair of tide-gates, which divides the lock in two sections; finally, at the inner end, one pair of tide and one pair of ebb gates.

The outlet sluice has, as also each mill-sluice, three pair of gates, viz: two pair of tide and one pair of ebb gates.

Hence there are in all twenty-seven pair, of which eleven of iron and sixteen of wood.

The lock-walls are built exclusively of ordinary brick-work, consisting of pressed bricks in the exposed faces; for the rest ordinary hard-burned bricks.

The hollow quoins, mitre-sills, stairs and copings, are made of common granite.*

The tide-shutters in the tide-locks and in the outlet-sluices are of iron. The ebb-doors, and all the doors of the mill-sluices, are of creosoted yellow pine.

Principal dimensions of the great tide-lock.

Length of the walls	130.00 metres.
Lock-pond, between the outer and inner points of the outermost mitre-sills	96.00 metres.
Width at the height of A. P.	18.05 metres.

Southern and northern tide-locks.

Length	99.30 metres.
Length of the lock-pond between the points of the mitre-sills	72.80 metres.
Width at the height of A. P.	14.05 metres.

Outlet-sluice.

Length	35.50 metres.
Width at the height of A. P.	10.05 metres.

Drainage-sluices.

Length of the walls	40.00 metres.
Width	4.00 metres.

The great lock-pond is divided by the middle tide-doors in two sections of 49.80 and 46.20 metres length.

* I observed Liege limestone, very much like Niagara limestone, used to a considerable extent for these purposes.—J. G. B.

The northerly and southerly lock-ponds, each in the same manner, in sections of 37.80 and 35 metres length.

Hence there are in all, six single or three double lock-ponds.

The small tide-locks are sufficiently wide to be used, *e. g.*, for the passage of the Hamburger steamers.

The height of the lock-walls is—

Outside of the outer tide-gates, 3.50 metres above A. P.

Between the outer and middle tide-gates, 2.50 metres above A. P.

Between the middle and inner tide-gates, 2 metres above A. P.

The different heights of the tide-gates correspond with those of the adjacent sluice-walls.

The ebb-gates reach only to A. P.

Above the draining-sluices a steam draining-machine, to drain the future basin of the Ij ("Ij boezem"), is in course of construction, designed and built by Messrs. Easton, Amos & Sons, London.

To each of the three draining-sluices belongs a pair of steam-engines, calculated at an effective of 75 horse-power.

The pumps are the so-called horizontal Appold's centrifugal pumps (combined engines), which raise the water just to the required height, since it is by the water itself that the guard-gates are opened.

The foregoing account, prepared for the information of a scientific body of Hollanders, leaves, very naturally, some matters unnoticed which are essential to foreigners for a full understanding of the character of the work.

Nearly all of Holland is alluvion; like the delta of the Mississippi and Nile, sedimentary deposits of the rivers which have thus raised the regions in the vicinity of their outlets to nearly the ocean-level, and created what may be called a debatable ground between land and sea, such as we may now observe, still unreclaimed, in the extensive areas of swamp and marsh which constitute the delta of our own great river. Along the sea-margin of this region in Holland, nature has erected a barrier in the almost continuous "duins" or *downs*—hillocks of sand thrown up by the waves and drifted

inward with the winds. This barrier has a width sometimes exceeding a couple of miles, and rises to heights of 40 or 50 feet.

The margins of the streams receiving the most copious sedimentary deposits, and hence more elevated than remoter areas, present not infrequently the only firm ground of a region otherwise naught but marsh, and form natural dikes against the overflow of their own waters or those of the ocean-tides. Thus, too, it happens that far the greater portion of the land is excluded from direct drainage into river or ocean, below the higher levels of which it is situated;* and can only throw off its surface-waters into the ocean by communications of its own through the sand-barriers, through which, in return, it is subject to daily overflow by the tides of the ocean, or, if above their level, to casual inundations by storm-tides. The inland basin of the Zuyder-Zee is, hence, the *natural* drainage-basin for the greater part of Holland; and it is through this estuary, now united to the North Sea by deep and permanent channels, that Holland is exposed to and has experienced the most formidable irruptions of the ocean-waves.†

From the southeastern extremity of the Zuyder-Zee an arm, known as the Y‡ (Het Ij), protrudes, with an easterly direction, towards the sea-coast; distant about twenty miles. It reaches almost to the very foot or landward slope of the downs, terminating in what is called the "Wijkermeer," from the margin of which to the sea-coast through "*Holland op zijn Smalst*"

* Many of the "polder" bottoms of Holland are in fact much below the level of low tides.

† The present condition of the Zuyder-Zee, as an estuary, appears to be the result of successive encroachments of the ocean, progressively occurring between the eighth and fourteenth centuries. The map of ancient Germany, in the Universal Atlas of Brué, represents an unbroken coast-line north of the Helder, where now are the islands of Texel, Vlieland, Ter Schelling, &c. Lake Flevo, as an inland lake, nearly identical in position and form with the present Zuyder-Zee, had a land boundary on the northwest from Enkhuizen (North Holland) to Stavoren (Friesland). This large inland lake discharged its waters into the North Sea by the river Flevium ("*vel* Rheni Ostium Orient"), which, issuing at a point midway of above-mentioned boundary, took a northerly course almost identical with that of the present "Vlie" channel (whence the name), debouching in the North Sea between the present islands of Vlieland and Ter Schilling. An expansion in the course of this river is represented as an island, in another map as a small lake; hence, probably, the mention of *two* lakes in some accounts.

The Yssel and Amstel, delta-branches of the Rhine, discharging their waters and sediments into Lake Flevo, are laid down as on modern maps. So, likewise, the Y arm; with this interesting feature, that from its western extremity *another* outlet is laid down ("Medium Rheni Ostium"), occupying nearly the track of the present canal from the Wijkermeer seaward. I am not aware that any trace of this ancient mouth is discoverable; but as the Rhine sediments would have been deposited in Lake Flevo, their absence from the sands of the coast-line would not be evidence against its former existence.

‡ English writers commonly render the name Ij by the English letter Y, and I adopt it in what follows.—J. G. B.

(*i. e.*, the narrowest part of Holland), the distance is less than four English miles.

Amsterdam, situated on this arm, is about four miles from its debouche into the Zuyder-Zee. The depth to the quays of the city, and for a short distance beyond, is considerable. Near the debouche, and in the contiguous portion of the Zuyder-Zee, is the "Pampus" bar, one of the most serious obstructions to the navigation. To the westward of Amsterdam the Y expands to a width of three or four miles, while its depth shrinks to 2 metres. In the Wijkermeer the depth is probably still less.

The superficial strata, through which the canal is made, consists, as in all alluvial regions, of mud, clay, and sand in various proportions. The bottom of the Y, where shoal, is covered with mud, beneath which are layers of clay and sand, very much as along the margins of the Mississippi. The sand-hills ("duins") which constitute the sea margin are, of course, sea-sand, extending to depths reached by trial borings.

The motives which have prompted the undertaking of this great work are set forth in what precedes. It only remains to furnish some few matters of information which, for reasons already stated, are not given in the very full description of the resident engineer, from which I have quoted.

One of the most important features in the actual project is the entire isolation of the canal from the Zuyder-Zee, by means of the great embankment or dam across the Y, from Schellingwoude to Paardenhoek. Not, indeed, until the public mind became reconciled to this feature (hostility to which had already, at an earlier date, interrupted one great enterprise for ameliorating the navigable communication of Amsterdam with the sea) could, as fully set forth by Mr. Dirks, an entirely satisfactory project for a *direct* communication with the ocean be devised. To leave the canal open to the fluctuating levels of the Zuyder-Zee—to interfere, by its construction, with the drainage system of the rich regions bordering the Y, while exposing them to dangers from which they were before exempt, involved so much that was objectionable—militated against so many interests—that projects, otherwise so meritorious as to receive the sanction of various commissions of engineers and scientific men, failed, as we have seen, for years, to secure legislative sanction.

The execution of this dam across a tidal channel of several metres in depth, involving the construction, in the midst, of a system of locks so ample that the barrier should not even be *felt* as an obstruction to the teeming navigation from the Zuyder-Zee; and of drainage, sluices, and machinery adequate to discharge all the rain-fall and surface water of the Y itself and of the extensive "polders" which border it, is one of the most remarkable and important features of the enterprise.

The general plan (Pl. I) shows the situation of the dam and the locks; and Pl. II, Fig. 2, gives an average cross-section.

The distance from shore to shore is 1,480 metres, of which, the locks occupying 120 metres, 1,360 constitute the total length of the dike. Of this length 300 metres connect the north shore with the locks, the remaining 1,060 metres extend from the locks to the south shore at Paardenhoek. The original soundings along the cross-section are not given; the locks were built in 3 metres of water, and in the gap, still open, there is said to be, as has been stated (p. 30), 5 and even 8 metres. The cross-section (Pl. II) indicates that the mean depth is $2\frac{1}{2}$ metres.

The bottom, swept over by the current of the Y, was probably not muddy, in the deeper portions at least, but, to the depths reached by the piling for the locks, or by borings, sand and clay in various proportions and stratifications. The ordinary tidal fluctuation is, here, about 1 foot ($0^m.30$), but storm tides sometimes reach a height of 1.50 metres* above A. P.

The dike is commenced by sinking to the bottom mattresses of fascine work, weighted with ballast-stone and long enough to stretch across the full width of the base. (See Pl. II, Fig. 2.†) Revetments of fascine work in narrower mattresses, sunk one above the other, are carried up along each margin to the level of A. P., between which clay and sand (the latter brought from the canal excavation through the downs) constitute the mass of the dike. A thickness of at least 1 metre of clay covers the embank-

* This is about the height reached (see p. 32) at the time of last injury to the coffer-dam; under exceptional circumstances the rise is believed to be greater. A memorandum taken on the spot mentions $2\frac{1}{2}$ metres.

† The making and sinking of these mattresses of fascines ("*zinkstukken*") constitute one of the important peculiarities of dike construction in Holland. I shall have occasion to allude to the subject more fully in another place.

ment, the slopes of which are temporarily revetted by osier-work and ballast-stone; to be replaced ultimately by a permanent stone pavement.

The most interesting facts in the planning and construction of the coffer-dam for the "Orange locks" have been already quoted from the paper of Mr. Dirks. The puddling between the concentric rows of piles was of clay brought from the vicinity of Amsterdam. Wherever iron bolts passed, under water, from one ring to the other, through the puddling, they were found to cause leaks, and their removal was necessary. The exhausting of the water from the interior of the dam was effected in four days by a small portable engine of 10 or 12 horse-power.

The excavation for the lock foundations was carried beyond 5.50 metres below A. P., the piles being capped at this level. The accompanying plan (Pl. VI) gives all the details of the pile foundation and timber-capping. On the original, from which this plan is copied, the estimated weight-bearing capacity of each pile is marked in figures, and they are all classified (a different color designating each class) according to their respective capacities. In the highest class are those which penetrated, *e. g.*, 11 centimetres under the last ten blows of the hammer, of 800 kilogrammes weight falling 4 metres; this is marked to bear 34 tons. In the lowest class, *e. g.*, 77 centimetres (about) is the final yielding of the pile under the blows. This pile is marked to bear 5 tons. Of course the different classes are indiscriminately mixed, the intention being to get the bearing capacity as nearly uniform as possible. To this end test piles were driven in different places to determine the lengths required to furnish the desired resistance. Wherever insufficient resistance was found—*i. e.*, wherever the penetration of these test piles exceeded 5 centimetres for the final volley of thirty blows of a ram of 800 kilogrammes falling 1.50 metres—the defect was remedied by increasing the number of piles.

For the ordinary driving the fall of this ram was 4 metres (13 feet 2½ inches); the resistance or weight-bearing capacity in kilogrammes was estimated by the simple and obvious formula*—

$$R = \frac{B\,H}{6\,e} \cdot \frac{B}{B + P}$$

* This is identical, except in the co-efficient of safety (the exclusion of which makes the expression that of the theoretical *bearing power*) with that made and used by me in pile-driving for the wharf piers of Forts Wadsworth and Hamilton. I drove to the resistance of about *three* times the intended load. At Fort Wadsworth the wharf, built fifteen years ago, has been severely tested without trace of settlement.

in which—

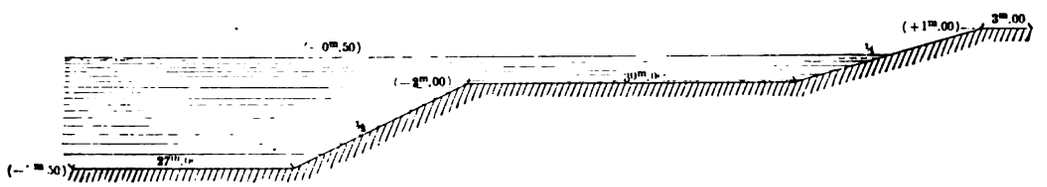
R = sustaining power of the pile.
H = height of fall of ram.
B = weight of ram.
P = weight of pile.
e = penetration effected by the last blow, the numeral 6, by which it is multiplied, being the co-efficient of safety. H and *e* must be measured by the same unit, whether it be metres, feet, or inches. The resistance, R, will be expressed in the same weight-unit in which B and P are measured.

The masonry construction for both these locks and the North Sea locks is so fully described in what I have quoted from Mr. Dirks, that I need not add anything in this place. In Appendix II will be found some particulars taken from the printed "specifications."

The weight of the iron gates is so nearly balanced by air-chambers as to relieve the hinges from strain and to render rollers unnecessary. All the gates are worked by chains and capstans, the use of thrust-bars being precluded by the narrow walls which bound the parallel lock-chambers.

The canal excavation through the downs from the North Sea locks to Velsen is, to the depth of 5 metres below A. P., done by hand, the material being thrown into rail-cars, by which it is transported either to the contiguous margins, or to wharves at Velsen to go into the dikes which extend through the waters of the Y. When the water is let in, the remaining depth of 2.50 metres will be excavated by dredging.

To make the dikes* bordering the canal through the waters of the Wijkermeer and Y, sand from the excavation through the downs is brought (according to the system now finally adopted and already described) to the wharves at Velsen, loaded on scows which are towed to the point where



needed. The dikes are raised with this material from the natural bottom up to $0^{m}.50$ below A. P.; ½ metre below the present mean level of the Y.

* Called by Mr. Dirks (p. 26) "canal and drainage dikes," since, by confining the canal within these narrow bounds, they enable the marginal sea-bottoms to be drained.

These dikes leave a wide berm (30 metres) between them and the canal excavation. This excavation now commenced by dredging-machines, the material being deposited upon the already made sand nucleus of the dikes. These wide berms are intended mainly to protect the dike-slopes against the wash of canal-waves. A temporary revetment of fascine or osier-work protects these dikes till the water surface between them shall be brought to its proper level (— $0^m.50$) and the external waters drained.

Through the sand-downs and outside of the sea-locks the sides of the canal will be revetted with stone for 1 metre above and below the water-level.

One of the important and characteristic features of the project is the drainage of the Wijkermeer and the Western Y. *How* important a change, this, in the physical features of the country, will be recognized by a glance at Pl. I. All the area covered by these waters, not included between the dikes of the main canal or those of its branches, will be drained and converted into habitable and arable land. This area amounts to 5,000 hectares (12,500 acres nearly). For this drainage, steam-machines (Appold's centrifugal pumps) will be erected at suitable points to lift the waters of the new-formed "polders" into the canal. Moreover, the canal becomes necessarily the recipient of the drainage of the extensive polders now bordering the Y, and it is a stipulation deemed, I believe, somewhat unnecessarily stringent, that the company shall maintain the level of the canal, including, of course, the open waters of the Y within the Schellingwoude dam, at the level of — $0^m.50$ below the present mean Amsterdam level, (A. P.)

Some considerable portion of this drainage can be effected through the North Sea locks at low tides—for the mean range of the sea-tide is from *minus* $0^m.50$ to *plus* 1 metre*—but even in ordinary weather the period of outflow will be too short, and, under the influence of winds, weeks, during which the gates cannot be thrown open, may elapse.

Hence the main reliance for draining the canal-basin is the powerful draining machinery consisting of three Appold centrifugal pumps, as already mentioned, connected with the Orange locks. They are estimated to be capable of discharging 2,000 cubic metres (74,000 cubic feet) of water per

* Storm-tides rise to 3 or 3½ metres.

minute; or of raising that quantity $0^{m}.50$, that being the average lift from the level of the canal to that of the outside water of the Zuyder-Zee.

The entire work of execution of the great enterprise, now far advanced toward completion, is performed under single contract* with the firm of Henry Lee & Sons, of London, whose capacity had been before proved through the successful construction of several of the great public works of England.

* The stipulated compensation in cash and securities amounted to 27,630,000 florins—in bonds, shares, and cash—estimated at 22,630,000 florins *cash*. The Dutch florin is equivalent to $\frac{40}{100}$ (nearly) of the gold dollar.

APPENDIX I.

"The diagrams of Pl. III illustrate a system of transporting earth from dredgers by the employment of a stream of water, produced by means of a centrifugal pump, which has been in successful action for upward of twelve months at the works of the Grand Canal of Amsterdam, in conjunction with the dredgers described at page 183, Vol. II, of this journal. The machinery has been designed and erected by Mr. Burt, under the direction of the contractor, Mr. Freeman, and has been patented in England in the name of Burt, to avoid affecting the patent previously taken out in Holland.

"In our engravings, Figs. 1 to 4 represent different views of one arrangement of the pumping machinery and pipes, while Figs. 5 and 6 show the apparatus as actually applied to the dredgers above mentioned. Fig. 1 is a vertical section, and Fig. 2 a plan of the machinery, *a a* being a cylinder fixed to the side of the dredger so as to receive the earth or material it is desired to convey, and *b* being the pump case fixed at its lower end. This pump case should be just below the level of the water from which the pump takes its supply through the water supply passage *c*, which is adapted to an opening in the bottom of the pump-case, and is fitted with a valve, *d*. This valve can be opened and closed by the lever d^1 and handle d^2; *e* is a bridge-piece fixed to the pump-casing and passing through the passage *c*, to carry the step or lower bearing of the pump axis *f*, which has also an upper bearing at the top of the cylinder *a;* and *g g* are bevelled wheels by means of which the axis *f* is driven. The pump blades f^1 are fixed on the axis *f;* and a^1 is an opening in the cylinder or receiver *a*, by which the earth or material is supplied to it by the dredger or otherwise. This opening should be 6 feet or more above the bottom of the cylinder or receiver. A conical valve or cover, *h*, is provided to regulate the passage of the earth or material from the cylinder through the opening in the top of the pump case; and this valve has two rods, h^1 h^1, fixed to it, and which pass through guides, *i i*, to a forked lever, *k*, to which they are jointed. The lever *k* extends out

through the side of the cylinder or receiver, and is jointed to a rod, *l*, which at its lower end is forked and holds a screw nut, *m*. This nut works on a screw, the stem of which is carried in a bearing, and has the bevelled pinion *n* upon it gearing with another similar pinion on the axis of the hand-wheel n^1, so that by turning this wheel the valve *h* can be raised and lowered; the valve is guided by the fixed guide-rods h^2. There is a tangential opening in the pump case *b*, which receives a casting, *o*, to which the pipes for conveying away the water and material are connected.

"A plan of the arrangement of pipes is shown on a smaller scale by Fig. 3. In this figure *p* is a wooden pipe made with staves like a cask, and bound together by hoops; it is connected with the casting *o* by a leather connecting tube, *q*, which is clipped on to the casting and on to the pipe by metal hoops drawn together by screws, as shown. At the other end of the pipe *p*, another leather tube, *r*, of some length, is placed, this tube forming a flexible joint, connecting it with the wooden pipe *s*. The tube *r* is kept in form by a coil of thin flat iron riveted to the leather. By similar flexible joint tubes the pipe *s* is connected with the succeeding pipes of the series *t*, *u*, and *v v v*, which series is continued to the shore where the material is to be deposited. Each of the pipes of this series is formed with floating pieces at its sides, as shown in section at Fig. 4, to sustain it in the water. The three tubes, *s*, *t*, and *u*, are combined together to make them more readily manageable in such a manner that, although the ends of the coupled pipe can be moved to and from each other, movement is restrained by booms, $w\ w^1\ w^2$. The centre and larger boom w^1 is pin-jointed at the centre to a float or saddle-piece at the centre of the pipe *t*, and the outer ends of this boom are pin-jointed to the booms *w* and w^2, the centre pins of the joints being fixed upon the floats *x x*. The other ends of the booms, *w* and w^2, are jointed at the junction of the pipes *p s* and *u v*, respectively. It will be seen that at each of these junctions, and wherever the flexible leather joint tubes are left free to bend the strain is taken off, the flexible tube by means of planks, *y y*, fixed on each pipe-float over the pipe, and pin-jointed together at their ends. When the position of the apparatus is such that the material does not require to be conveyed over water, there may be substituted for this flexible system of floating pipes any ordinary arrangement of tubing.

"Figs. 5 and 6 represent, as we have said, the apparatus as actually used in Holland. In this case it will be seen that a modification of Woodford's pump is bolted to the side of the dredger, and driven at the rate of two hundred and thirty revolutions per minute by the same engine, by means of the bevel gearing shown on the top. The pump, which is 3 feet 6 inches in diameter, is fixed with the top on a level with the surface of the water, and is furnished with two inlets protected by valves, the one on the bottom for admission of water, and the other on the top for regulating the entry of the material to be transported. On the top of the pump is placed a cylinder or reservoir, to receive, by means of a shoot, the stuff dredged up.

"The dredger is connected with the shore, or depot for the material, by means of wooden pipes fitted, as we have already described, with buoying pieces to enable them to float, and connected by leather joints; those immediately following the dredger being arranged on the lazy-tongs principle, to admit of its free movement in any direction. The leathern joint-pipes for this portion are about 4 feet 8 inches long, strengthened and compelled to assume a regular curve by iron spirals riveted to their outsides; but the joints for the intermediate pipes are only about 18 inches long, just enough to allow of a firm connection being made by iron hoops tightened by screws. The diameter of the pipes is 15 inches.

"The action of the above arrangement is as follows: By the revolution of the flyer, A, a rapid stream of water is maintained through the pipes, into which the dredged stuff is admitted through the pump by the opening on the top, and is thus rapidly mixed and carried to the delivery at the opposite end of the pipes, where the heavier materials deposit themselves in nearly level beds. An arrangement might also be made by causing the pipes to discharge into an enclosed area and running the water from the top, by which means any required thickness could be deposited.

"The great advantage of this system is that it admits of a continuous working of the dredger; and the connection with the point of discharge, by means of pipes, does not in any way affect its free movements within very considerable limits. Four dredgers, fitted on the above system, are in operation at the Amsterdam Canal, working night and day; the large ones being capable of lifting 1,700 tons each in twelve hours, corresponding nearly to

1,330 cubic yards of sand mixed with clay to the extent of about 50 per cent. This amount has been transported in some cases to a distance of 300 yards, with a lift of 5 feet, and from the fact that a 100 yards, more or less, of pipe upon a level, making no perceptible difference in the working of the system, it is inferred that by increasing the velocity of the flyer to overcome the slight extra friction in the pipes, the distance through which earth could be transported might be increased to any reasonable extent. Mr. Hawkshaw, we should state, is the engineer-in-chief of the Grand Canal works, while the resident engineer is Mr. Dirks, and the contractor, Mr. Freeman." ("*Engineering*," *July* 10, 1868.)

APPENDIX II.

The following extracts from the specifications concerning the North Sea locks are given:

"The walls are continuous throughout, except the south wall of the south lock, in the centre of which, instead of vertical walling, the ground is sloped along the chamber.

"The walls must be built throughout of second class brick-work, faced with first class of the same.

"The hollow quoins, pointing-sills, steps and copings, will be of ashlar masonry, the stone being of English Bramley Fall from the best Yorkshire quarries, or other stone of equal quality from Belgian, English, German, or Norwegian quarries.

"The bottom of the lock-chambers, also the eastern and western aprons, and the bottom of the side channels, will consist of fascinage, broken bricks, and basalt pitching. The connecting slopes and the slope in the south lock will also be pitched.

"The gates pointing seaward will be of iron. The remainder will be of creosoted yellow pine.

"The lock-gates will be provided with proper sluices, and will be opened and shut by machinery, there being one machine to each leaf of each gate.

"The sand or other material, which might be excavated or dredged underneath the foundations or the places of the fascine works and stone pitchings, is to be removed and to be replaced by first class clay, thoroughly puddled.

* * * * * * *

"MORTAR.

"The mortar is to be made in the mode the engineers may direct, either of three measures of sharp sand and one measure of Portland cement, or of

three measures of Tournay third-class stone-lime (slacked on the works), two measures of Andernach trass, and one measure of sharp sand.

"The ingredients are to be accurately measured, then mixed, tempered and worked with as little water as possible, until brought to a tough and proper consistency.

"Proper measures are to be provided and used for ascertaining the proportions.

"CONCRETE.

"The concrete will be composed of one measure of Portland cement, four measures of sand, and five measures of shingle.

"The concrete is to be made in the following manner: The materials having been measured, are to be well mixed with a due proportion of water, and the whole well worked together and put into the work immediately it is mixed.

"Sheds for the cement are to be erected near the site of the work.

"PORTLAND CEMENT.

"The Portland cement is to be of the very best manufacture from the Thames, or other Portland cement of equal quality suited for the work.

"It is to be ground extremely fine, and is to weigh not less than 115 English pounds per bushel, and each cargo will be tested in the following manner: The cement is to be made into small blocks of a convenient size, and after forty hours they are to stand a tensile strain of not less than 112 English pounds per square inch. Again, the blocks are to be immersed in water, and after seven days they are to stand a tensile strain of not less than 200 English pounds per square inch. Slabs or cakes are also to be made and placed in water, and after immersion for twenty-four hours they are not to show any signs of cracking or any softness on the surface. No cement is to be used until after it has been in the sheds for at least one month, unless the engineers shall otherwise permit, and they will, if they think fit, order this time to be lengthened."

* * * * * * *

A modification of the above provides that—

"The concrete will be composed of one and a half measure of Portland cement, three and a half measures of sand, and five measures of shingle.

"The concrete is to be made in the following manner: The materials having been measured, are to be well mixed with a due proportion of water, and the whole well worked together and put into the work immediately it is mixed."

* * * * * * *

For the Orange locks the same specifications apply, except that for the smaller sluices the bottoms have brick inverts (not shown in the plans, Pls. IX and X).

It is provided that the wooden gates shall be of "*red pine or American yellow pine, both creosoted.*"

In the latest "specifications" concerning the harbor-pier construction (dated, however, May, 1869), it is prescribed:

"*From the bottom up to the level of at least* 0^{m}.15 *above A. P., the breakwaters are to be built of blocks of concrete.*

"*The bottom courses, according to the option of the contractor,* either *to be sunk below the surface of the sand,* or *to be set on the bottom and to be levelled, consecutively to the shifting of the sand,* or *to be placed on a level bed of basalt or other stone, filled up, if necessary, with broken bricks.*

"*The first courses may also be placed somewhat irregularly, provided that at the depth of* 0^{m}.70 *or more below A. P. the blocks be thoroughly levelled and trimmed, so as to allow the building of the remainder of the work in accordance with the approved drawings.*

"Above the level of *at least* 0^{m}.15 above A. P., the work will be faced with concrete blocks, backed *either* with a hearting of concrete *or with hearting blocks.*

"The outside or facing blocks will be composed of *ten measures, viz: One* measure of Portland cement, *four* measures of sand, *two* measures of hard-burned clay as a maximum, and *three* measures of broken bricks as a minimum.

"Should occasion require it, the engineers will alter the above relative proportions of sand and shingle, and sand and burned clay or broken bricks, and in order to arrive at data for determining suitable proportions, the contractors are required to make such experimental concrete and concrete blocks as the engineers may think necessary

"The whole work below low water is to be set by means of diving-bells or diving-helmets; and the contractors are to afford the engineers and their assistants the use of the diving-bells and helmets, boats, and other apparatus, with the men for working the same, when required."

The following notes of prices were taken: Wages of laborers, per day, 1½ florins; wages of skilled labor, 2½ florins; bricks, per thousand, 12 florins, or 22 florins per metre cube; Liege limestone (dressed), 50 florins per metre cube; rubble stone (basalt), 5 florins per English ton; gravel, 4 florins per metre cube; timber (pine), 1 florin per cubic foot; timber (oak), 3 florins per cubic foot.

IMPROVEMENT OF THE NAVIGATION FROM ROTTERDAM TO THE SEA.

A glance at the map (Pl. VII) will best show the relations of the important seaport of Rotterdam to the remarkable reticulation of fluvial channels, by which the waters of the Rhine, the Meuse, and the Scheldt mutually communicate and discharge themselves into the North Sea.

Although the "Nieuwe Maas," upon the bank of which the city is built, appears to be the most direct channel of discharge for the waters of the Rhine,* it will be seen that instead of this comparatively direct communication with the sea, access for sea-going vessels of large draught has to be sought by the way of the distant harbors of Brouwershaven or Goeree, and through intricate shoal-beset channels or through an artificial canal.

A brief description of the actual routes of sea communication will best serve to an understanding of the motives prompting, and the character of, the work now in progress.

The existing routes taken by sea-going vessels in reaching or leaving Rotterdam, are as follows:

I. The shortest and most natural route is to follow the Nieuwe Maas by Maassluis or Brielle, between the Hook of Holland and the island of Voorne.

In earlier days this channel was generally used; and there appears to have been, formerly, greater depth on its bar than at present. It is still in general use both by steamers and sailing vessels not drawing more than 3 to 3½ metres (10 to 11½ feet). It is the usual route of most of the sea

* The ancient arm of the Rhine, which alone, through the Netherlands, bears the name of the Rhine (or sometimes the "Old Rhine"), has long since ceased to be an outlet of the river waters. Its mouth, at Katwijk, is closed by guard-locks (see Appendix III), and its channel serves for drainage of contiguous "polders," among which is a large portion of the drainage basin of the bed of the former Harlem Lake. The Gueldrian "Issel" and the Amstel, small delta arms of the Rhine, discharge into the Zuyder-Zee—the latter at Amsterdam. The main body of the Rhine flows by Rotterdam under the name of the Nieuwe Maas.

steamers, with favorable weather and high tide. With strong westerly winds the sea runs so heavily upon the entrance-bar that the passage becomes impracticable.

II. By the Nieuwe and Oude Maas, Dordrecht-Kil, &c., vessels descend the Nieuwe Maas as far as Vlaardingen, ascend the Oude Maas, and pass through the Dordrecht-Kil into the Holland-Diep. After passing through the Holland-Diep this channel (or route) divides into two, one following the "Haringvliet" and outlet of Goeree ("Goeresche Zeegat"); the other through the flats of Ooltgensplaat, the Volrak, the Krammer, the Grevelingen, and through the Brouwershaven Pass to the sea.

There are shoals in the Oude Mass, near the Beer and the Lindt, on which, at low water, there is but $2^m.5$ to $2^m.6$ depth. In front of Hellevoetsluis there is a shoal (the Zuider-Pampus) with about $3^m.9$ depth; farther seaward the Noorder-Pampus has $3^m.6$, and over the Slickgat is about the same depth. The channel between these two shoals is narrow, so much so that it is with difficulty navigated by sailing vessels. Over the bar there is but $5^m.7$ depth with ordinary high water, and skilful pilotage is needed for the passage.

The channels, through the flats of Ooltgensplaat to the Brouwershaven Pass, are subject to continual changes. The deepest (1858) is the Hellegat, in which, at ordinary high water, is $5^m.2$. Previously to 1855—for many years—this channel was innavigable; during which time the "Oudegat," though narrow and winding, subject to cross-currents and of very difficult navigation, was used. The Brouwershaven channel is otherwise navigable for vessels of the greatest draught, there being at ordinary high water $11^m.80$ over the bar.

III. From Rotterdam through the "Noord" by Dodrecht to the Goeree Pass. Principally used by vessels of small draught, there being many shoals, especially in the Noord.

IV. From Rotterdam down the Nieuwe Maas to Vlaardingen, thence by the Oude Maas, the Spui, and the Goeree Pass. But slightly more practicable than the preceding, on account of shoals in the lower part of the Spui—used occasionally by light-draught vessels, especially steamers.

Owing to the unsatisfactory character of these four (or rather five)

routes of navigation, tortuous, beset with shoals, leading sometimes up and sometimes down stream, the canal of Voorne was constructed in 1827–'29, and has been since in continual use. (See Appendix II.)

Its length is about eight miles, with locks at each end, and affording passage to vessels 71 metres length, 14 metres breadth, and $5^{m}.15$ draught. The ordinary surface level corresponds to low water at Hellevoetsluis; it can be raised, if required, to $1^{m}.80$ above that level, so that as far as draught is concerned the canal offers no obstruction.

But though the idea governing the construction of this canal was to enable the largest vessels, fully loaded, to pass from Rotterdam to the sea, the subsequent increase in the size of sea-going vessels soon developed the fact that the depth of water on the bar and shoals of the Goeree Pass was inadequate—the length of the locks of the canal insufficient.

At present large vessels of great draught enter the Brouwershaven Pass, discharge part of their cargo into lighters, and then proceed, sometimes outside by the Goeree Pass, but oftener by the interior passage to Hellevoetsluis and through the Voorne Canal to Rotterdam.

Various projects have been made since the execution of the Voorne Canal for obviating the defects attending the navigation of that route. One of these by a former chief engineer of the Waterstaat, Greve, consists in the construction of a jettee, starting from the island of Voorne (see Pl. VII) toward the shoal of the Hinder, thence, making an elbow, running parallel to the Goeree shore, and terminating in the sea at the line of 5 metres below low water, or 7 metres below ordinary high water. This jettee—nearly nine miles long—would have cost 7,500,000 florins.

It was also proposed by Mr. Greve, and Mr. Conrad (an engineer of the Waterstaat), to construct a new canal through Goedereede connecting the Haringvliet with the Springersdiep, and thence leading to the Brouwershaven Pass. In connection with these projects it was proposed to increase the length of the locks of the Voorne Canal, and also to make various improvements in the river navigation, by closing of unused channels, or by jettees or natural dikes.

Another project made by Chief Engineer Greve, in 1857, by order of the government, was to improve the entrance to the Nieuwe Maas by the

construction of two dikes of fascine-work, the northern one starting from the Hook of Holland in a southwesterly direction, gradually curving to westerly, and extending to the depth of 5^{m}.50 below ordinary low water. The southern one to start from the island of Voorne and, approaching the first, to run parallel with, and at a distance from it, of 750 metres, till it reached the depth of 5 metres.

The total length of the two would be about 18,850 metres—height above ordinary low water 2^{m}.75, or 1^{m}.25 above ordinary high water. This work was estimated at something more than 9,000,000 florins.

A plan for the same object and very similar in character, but much less expensive—the piers being lower and shorter—was made about the same time by the engineer of the Waterstaat, Caland.

A year or two later (1858) the same engineer presented to the Waterstaat a plan differing from the two just described, in these important particulars, that the northern arm of the Nieuwe Maas, the "Scheur," is followed, and, instead of attempting to obtain an outlet through the old mouth and over the old bar, a cut is proposed through the Hook of Holland directly to the sea. (Pl. VIII.) The plan also contemplates the improvement of the whole river from Krimpen to the sea by means of lateral dikes (*strekscbe dammen*) for modifying the directions of the currents and correcting the immoderate channel widths, and by augmenting the same when too contracted.

The great advantage which this plan possesses over the others consists mainly in this, that the depth of 5^{m}.50 at ordinary low water can be reached with piers together only 2,600 metres long, while the other projects require 18,850 metres length of piers to reach 5 metres depth, the construction of which would, moreover, have been more difficult.

In addition to this the "Scheur" branch of the Nieuwe Maas is more regular and better adapted to becoming a great navigable channel than the southerly branch which passes by Brielle, and this superiority will be increased when, by digging through the easterly point of the island of Rosenburg, the waters of the Oude Maas are thrown into the Scheur, and when the strong ebb-current from the Oude Maas through the Spui is checked, as is proposed in the plan.

The commission of the Waterstaat, from whose report the foregoing has been condensed, makes the following critical comments upon the projects described. The plan of M. Greve for the improvement of the Goeree Pass involved a very great expense, while the desired result could not be regarded as certain. The projector himself subsequently gave preference to the project for a canal through Goedereede to reach the harbor of Brouwershaven.

To this canal project it is objected, in addition to the admitted inferiority of canal to open river navigation, that the Zuider-Pampus shoal in the Haringvliet is a formidable obstruction in this route, the practicability of the removal of which is by no means assured, while without this removal the canal would be useless.

The commission object to the plan of Chief Engineer Greve for the improvement of the Brielle Pass—

1st. That it is not founded upon the fact that it is the movement of the tides mainly that is influential in maintaining depth in the outlets of rivers, and hence has not provided for the free admission of the tidal flow.

2d. That to the jettees are given the height of storm-tide, by which the expense is greatly enhanced and the work needlessly exposed to injury.

3d. The great length of the piers and the great difficulty of their execution, situated, as they are, upon the existing shoal (or bar) on which the breakers are violent during moderately strong westerly winds. The same remarks apply to the first plan of the engineer, Caland, with the qualification that the lesser height diminishes the expense and affords less exposure to injury from wave-force.

The second plan of the engineer, Caland, was adopted with but slight modifications by the commission, and is now far advanced in successful execution. In connection with its adoption of this project, the commission presents, as applicable to it and to the general subject of the improvement of the navigation into the mouths of tidal rivers, the following "general considerations:"

"Theory and experience have taught, and the documentary information forwarded to the commission, as well as the observations of our fellow-member, Caland, upon our tidal outlets, confirm their testimony; that the most influential agent in maintaining the depth of our navigable channels is to be

found in the *velocity* with which the water moves through the channel section. When velocity and volume of water are insufficient with regard to the profile, a constant regimen cannot exist.

"If these cannot be increased sufficiently to maintain a profile adequate to the needs of commerce, the end can only be attained by dredging or by a resort to artificial canals.

"The incessant action of tides and waves maintains in constant motion the sands and rocky fragments along our coasts, establishing a bottom slope of from 250 to 140 base to 1 rise, between the Hook of Holland and the Helder, so that no nearer than 800 to 1,300 metres from low-water line can a depth of $5^{m}.50$ be found; or of 7 metres below high water, the depth needed for large vessels.

"The drainage water which flows down our rivers is, owing to the immoderately great profiles of the mouths, quite inadequate to maintain, through this slope of the shore, a channel of sufficient depth for the passage of large vessels; but the tide enters the mouths and, during ebb, is discharged along with the accumulated drainage water, of which, however, its volume is many times greater. Hence it is comprehensible that it is to the action of the tides mainly that the maintenance of depth in our river-mouths must be attributed.

"The total effect depends upon the velocity and volume; both increase with the tide-range, that is, with the difference between high and low water. Hence it is found that the entrances of our rivers increase in depth in going southward. At the Brielle outlet the tide-range is $1^{m}.65$; the low-water depth 2 metres. At Goedereede the average range is $2^{m}.10$, and the minimum low-water depth $3^{m}.6$.

"At Brouwershaven the range is $2^{m}.80$, and the minimum depth 9 metres.

"In the Roompot the range is 3 metres; the depth at low water $8^{m}.40$.

"In the entrance to the Western Scheldt the average range is $3^{m}.70$, and the depth in the Melingen Pass (one of the three main passes of this entrance) still $7^{m}.60$. When we consider the insignificant volume of the surface drainage of the Scheldt, it appears very clear that these waters have slight influence in maintaining the depth of their entrances.

"Another illustration is afforded by the Gueldrian Issel, which discharges into the Zuyder-Zee where the tide-range is but $0^{m}.20$. This mouth can be maintained navigable, for the small craft which use it, only by artificial means. Other instances may be cited in the rivers which discharge into the Mediterranean, where the powerful influence of the tide is lacking; but we believe enough has been said to justify our opinion that the tidal action is the efficient means of maintaining the depth of our river entrances.

"It is not in the power of man to increase the tidal range; but the direction and form of the entrance may be regulated and the breadth limited to due proportion to the volume, and thus the depth may be increased.

"The outlets of our rivers in the North Sea have all (some more, some less) a curve to the southward, whereby they better intercept the tidal current flowing from out the channel.

"The shortest line to reach the required depth is directed northwestward, because the coast line lies northeast; but as the tide-stream comes from the southwest, the direction of the entrance should lie, at least, east and west.

"Rivers do not discharge the same volume through every profile, but the nearer the sea the greater the volume. Hence, to maintain an equal depth, the width must be the greatest at the outlet, diminishing funnel-wise in ascending.

"LATERAL DIKES (*Streksche dammen*): *externally*, it is out of the question to employ anything else than such dikes or piers. Such have for a long period existed at the two entrances to the Gueldrian Issel, the Ketel, the Ganzediep, and at the entrance to the Zwartewater in the Zwolsdiep.

"Inland it is more common to limit the breadth of rivers by jettees of crib-work (*dwars-kribben*), and we are far from condemning this, frequently less expensive, method; but we consider it undesirable for the lower rivers, since between the cribs there remain basins (or areas) which the tide must fill to the prejudice of its upward flow. The farther up the tide can be enticed, the more powerful will be the downward flow of the ebb; hence, in our plan, we give the preference to lateral dikes."

In adopting, in its main features, the project of Mr. Caland, the commission remarks that the improvement of the Brielle outlet is closely connected

with that of the river up to and above Rotterdam, which consists in promoting regularity in the channel by application of lateral dikes to contract it when too wide, and by excavations when too narrow. The width is fixed at 225 metres at Krimpen (Pl. VIII), regularly increasing to 450 metres opposite Vlaardingen. Below Vlaardingen the ebb and flow of the Oude Maas, by cutting through the eastern point of Rosenburg Island, is thrown into the Scheur. This necessitates an increased width below Vlaardingen, and at the commencement of the piers it amounts to 900 metres.

The widths are fixed in the assumption that, owing to the removal of the existing contractions, particularly those at Rotterdam, Charlois, and between Rotterdam and Krimpen, the tide-water will ascend higher and need larger cross-sections, which are also needed in the last-named portion, to relieve the flow of the Lek.

For the heights of the lateral dikes the mean between high and low water is taken; a greater height would diminish the quantity of tide-water entering; less height would diminish the effect of the ebb currents, especially over the entrance. It may be true that high dikes, by preventing the filling lateral areas, cause a somewhat higher ascent of the flood, but that is not needed in this case, since none of the existing shoals to be removed are remote from the entrance; moreover, the height of the dike can be at any time increased if it hereafter appear desirable.

The profile of the dikes from Krimpen to the Hook of Holland, where not a part of the shores themselves, is adopted as follows:

Top breadth 3 metres, with slopes on the river side 1 upon 1, on the land side $\frac{1}{2}$ upon 1, with berms on the river side of 5 metres near Krimpen, increasing to 15 metres at the outlets; landward berms, 2 metres width.

The dam across the existing Scheur (at A, Pl. VIII) is to be raised above high water, so that the entire ebb flow may be forced into the new mouth. The profile is fixed as follows (Fig. 1, Pl. IX):* Top breadth, 5 metres at $1^{m}.50$ above ordinary high water, with slopes above mean low water of $\frac{1}{4}$ upon 1; below that level of 1 upon 1, with berms projecting on each side 15 metres. The profile is made the same on each side, because during construction it will be equally exposed to flow and ebb tide currents.

* In construction, this profile became importantly modified by force of circumstances, as will be seen pp. 67, 68.

Along the new river through the Hook of Holland and connecting with the "downs," high dikes on each side, with the necessary foreland (*ter wederzijde met het noodige Voorland*), well elevated above storm-tides, are proposed for the double object of making a suitable connection with the entrance-piers and of providing, very near these piers, areas of land free from overflow, where, during such tides, materials and men can be in security, (see Fig. 2, Pl. X). The adopted profile of these dikes is as follows: Height, 8 metres above mean low water; top breadth 5 metres, with slopes on the north side of five times, and on the south side three times the height, descending to $1^{m}.50$ above mean high water. At this height berms are projected, on the sea side of 12, on the river side of 8 metres width, having an outer slope of 1 upon 4. The outer slopes of these berms, from $0^{m}.50$ below the strand surface upward, to be revetted with stone, as also the berms themselves and the slopes above them on the two sea sides, to 4 metres above mean high water for a length of 2,000 metres measured from the low-water line on the North Sea inwards. The remaining parts of the profile of the dike to be covered with sods.

Finally, the two jettees in the North Sea, which will constitute the proper river mouth, are to consist of fascine-work with stone, to have a total length of about 2,800 metres, the northern pier reaching to $6^{m}.50$ below mean low (or $8^{m}.20$ below mean high) water, and the southern one so much shorter that, thereby, a tide-catching form is given to the entrance.

At the outer extremity the northerly pier will have a height of 1 metre below mean low water, which from thence gradually increases shoreward to 1 metre above mean high water at the high-water shore line. From thence it connects with the shore dike by a rise of 1 to 10. The southern pier to be, throughout, $0^{m}.50$ lower than the northern one.

The cross profile to have a width at top of 10 metres. The top to be rounded or curved $0^{m}.50$, the specified heights attaching to the middle line. On each side, slopes of 1 upon 1 down to berms.

The section of the jettees varies somewhat, but the following particulars, taken from the specification for the construction of the pier-head and last 200 metres of the southern pier, will afford an adequate notion of the construction:

The "cross-section" (Fig. 1, Pl. XI) is through the jettee, near the pier-head. The central line of top at the point taken is $1^m.80$ above mean low water. The top surface is rounded down $0^m.75$. The sides slope 1 upon $1\frac{1}{4}$ on the entrance side; 1 upon 1 on the sea side. The end slope of the pier-head is 1 upon 8.

The lower layer of mattresses extends 10 metres on each side beyond the intersection of the side-slopes prolonged; the layer above, 5 metres.

To form the pier-head the top is widened and extended, as berms, on each side of the end of the pier proper, as shown by "plan" and "cross-section" of pier-head, Pl. XI.

The "*zink-stukken*" (or mattresses of fascines) must not have less than 400 square metres superficial area, nor more than a half metre thickness at the sides. They are to be sunk so that they shall connect closely and lap joints from course to course. When sunk in more than $2^m.50$ depth they must be lowered by sinking lines. They are to be loaded with at least three-fifths of a ton (English) of stone per cubic metre of fascine-work.

Above low water the fascine-work appears to be laid in separate fascines by hand, the cross layers having the bands cut open. These, like the "*zink-stukken*," are loaded with stone; rubbish inside, but stretcher-stones of the height of the layers along the external edges.

The pier is consolidated by oak piles from $9^m.50$ to $11^m.50$ long, driven through all the layers into the bottom. The tops of these are at $3^m.75$ above low tide, and are framed together and form the supports of a platform above which, during construction, a rail track is laid.

The fore-berm and slopes surrounding the pier-head are further secured by oak piles in three rows, framed together as shown in Pl. XI, Figs. 2 and 3. This palisading of the fore-berm contains 800 oak piles, each $4^m.50$ long.

The whole top surface of the piers and pier-head, including the fore-berms, are to be covered with regular Doornik stone* (or stone of equal quality), to average for the pier 14 inches ($0^m.35$), and for the pier-head and berm 20 inches ($0^m.50$) thickness.†

*A limestone from Doornik, Belgium, somewhat similar to our Niagara limestone.

†Fig. 1, Pl. X, is a cross-section of the south jettee, in which the combination of fascine-work and stone is exhibited to the eye: with a projection of the pier-head and beacon-light at the extremity of that jettee.

As soon as a portion of the pier is completed to above low tide, ballast-stone is thrown in upon the base-berms and sides to an amount averaging 30 to 35 tons per running metre of each side-slope and base-berm.

No stone to weigh less than 50 kilograms, and from low water up to top pavement they are to be carefully laid, and their joints packed with smaller pieces and rubbish.

Between the rows of piles around the fore-berm of the pier-head, stone must be placed weighing at least 500 kilograms, and outside, along the outer row of piles of said berm, there must be put, along low-water line, at the top of the stone covering already mentioned, at least one row of stones of a minimum weight of 1,000 kilograms.

For a better understanding of the construction and placing of the mattresses, which are the essential feature in the construction of these jettees, the following account is taken from the works of A. Caland* and Storm Buijsing†:

"*Zink-stukken*," which I will call "mattresses,"‡ are always made on the sea-beach between high and low water, so that after completion they can be floated off at high tide. They consist, in the first place, of a grillage of fascines, of which the lowest layer is laid across the breadth at distances of $0^{m}.9$ to 1 metre. At right angles to this layer is laid the second or longitudinal layer of fascines, at distances apart never more than $0^{m}.90$, since longitudinal strength is needed in pieces which are to be sunk. These should be as long as possible, and where they are joined short fascines are laid and bound, overlapping their ends; or they may be united by cutting open the end binding-withes and interlocking the ends for a length of $1\frac{1}{2}$ or 2 metres, and binding this junction with the necessary cross-bands or withes.

* Handleiding tot de kennis der Dyksbouw en Zeeweringkunde, 1833. The author, former member of the Waterstaat, was the father of the present distinguished chief engineer, P. Caland.

† "Waterbouwkunde," 1854, D. J. Stormbuijsing (deceased). One of the most distinguished hydraulic engineers and members of the Holland Waterstaat.

‡ I use the word for "*zink-stukken*," the technical term by which these constructions are known in Holland, to which country they are peculiar. It is, however, to be remarked that they make a distinction between "*rijzen-bedden*," which are simply laid in dikes, and "*zink-stukken*," which are *sunk* from the water-surface to their place. The first term would better correspond to the English word mattresses. The things indicated differ very little. To the former is given more transverse strength; to the latter more longitudinal.

At each crossing these fascines are bound together with one or two flexible withes, with the exception of those at the periphery and alternately from within, which are made fast with tarred ropes from old ships' cordage. These ropes are cast around a stake, so that they can, after the filling up of the mattresses, be made fast to the upper grillage or layer of fascines.*

On and perpendicular to the lowest layer of fascines are now placed loose layers of osier or bundles, of which the top ends are in succession covered by the root or stem ends of the layer above, so that the longitudinal fascines are thus embedded in this layer of osier. Perpendicularly over this is a second layer, called the filling layer ("*optreklaag*"), of which the top ends are above.

Over this filling layer is laid the longitudinal fascines of the upper grillage, and thereafter the space between these fascines is filled with a second filling layer (*optreklaag*), over which finally the cross-fascines are laid in such a manner that the intersections (with the longitudinal fascines) come exactly above those of the lower grillage, of which the stakes above-mentioned (having the binding cords about them) serve to mark the position.

These crossings of the upper grillage are now bound with these same cords, by which the osier filling is compressed as tightly as possible between the two grillages. The other crossings are, as in the lower grillage, stiffly bound with two withes. The stakes are now withdrawn.

These three layers, well compressed, should make a mattress of from $0^m.40$ to $0^m.60$. The thickness and strength may be increased by applying more layers. It is to be observed that the "*rijzen-bedden*" require the most strength over the breadth, and hence that it is best to make the number and thickness of the cross-layers greater than those of the longitudinal. In case of more than three layers it is advantageous to strength that the two middle ones should cross one another obliquely to the length of the mattress.

The "*zink-stukken*" require the greatest strength in their longitudinal

* These fascines (*wiepen*)—or saucissons, as they may be called if reference is had to their great length—are made of willow or copse-wood, and the process of making is quite similar to that employed for the objects bearing those names in military technology. Their length generally exceeds that of the so-called "saucisson," as it must exceed that of the length (or breadth) of the mattress of which it forms a constituent. They measure, according to Caland, 30 to 45 centimetres in circumference, corresponding to diameters of say 4 to 6 inches. According to the same authority it would appear that the binding-withes are only six inches apart.

rather than in their cross dimensions. Hence the distance apart of the cross-fascines is usually from $0^m.90$ to 1 metre, and that for the longitudinal ones never more than $0^m.90$, and very often still less. The lowest layer of fascines should not be permitted to lie across the stream or current, for in that case the "*zink-stukken*" would be easily undermined.

The magnitude of these pieces is regulated according to circumstances, though neither for these nor for the mattresses is it unlimited, since they would become too unmanageable for transportation to their destined points and for sinking with accuracy in accordance with the projected plan. The largest pieces that are sunken have a breadth of 15 to 16 metres, and a length of from 150 to 180 metres. Their thickness, as that of the mattresses, varies between the limits of $0^m.40$ and 1 metre. If given greater thickness they become too stiff and lose their aptitude for conforming to the inequalities of the bottom.

As the "*zink-stukken*" are destined to be sunk and held to the bottom by means of ballast, the upper surface is provided with *pens* (or enclosures), in order to keep the ballast in place should the bottom be sloping. These pens are formed of rows of hurdle (or wicker) work; first, two extending around the periphery of the piece, parallel and at a distance apart of $0^m.90$ or 1 metre, according to the distance of the fascines, with which these hurdles forming the "gangway" ("*gang boord*") must correspond.

Transversal and longitudinal hurdles are likewise placed upon the interior longitudinal and transversal fascines connecting with the inside hurdles of the "gangway" row. At every fourth stake of the cross-hurdle is driven an anchor-stake to prevent uplifting.

Whenever the "*zink-stukken* " are to be placed along a steep shore, the depth of the "pens" can be increased by not sinking the lower course of fascines of the upper grillage-work into the osier filling, but laying it on across the upper layer of osier filling. On account of the stretching which very large pieces undergo in floating to position and in sinking,* it is a necessary precaution to allow, in weaving the hurdles, room about the stakes, so that they shall not be pulled loose by the extension.

It is of importance that the stakes about which the hurdles are woven,

* This is said to amount sometimes to one-fiftieth of the linear dimensions.

though well driven into the piece, should not pass through the lower grillage, since in touching bottom they might be forced loose, or perhaps cause cavities under the piece, through which the water would find final passage.

At the third or fourth intersections of the fascines from the corners, and again for long pieces at about 15 metres apart, are driven holding-posts ("*proppen*") into the upper grillage. These consist of 12 or 14 stakes which are driven closely, crosswise and oblique to each other, and held very firmly in the piece, as they serve to hold the cables and cordage by which the pieces are floated to their position. Finally the piece is provided with some loops of stiff cordage, through which to run the ropes by which the piece is lowered or sunk to the bottom. The crossings where these loops are attached are, for the sake of security, connected with the lower grillage by double ties of rope, since the whole weight of the ballasted piece bears upon these points.

When the piece has been floated over the place where it is to be sunk, and, with the requisite sinking-lines, made fast to previously-anchored vessels (sometimes, also, on one side to the shore), there is commenced over the whole surface, but chiefly in the middle, the loading or ballasting with clay or gravel held in readiness in small vessels placed along the edge.

The piece, somewhat bent down in the middle and brought to bear upon the sinking-ropes, is so allowed to remain until the moment of still water arrives, in order that the sinking may take place without danger of displacement by the force of the current. At a given signal more ballast is, from all sides, cast on the piece; the sinking-lines are simultaneously payed out so that the piece, without overturning, may take the ground as equally as possible at all points. As soon as it is ascertained that the piece rests on the bottom the sinking-lines may be detached, but the casting of ballast is not slackened until, by sounding, it is ascertained that the piece is entirely covered.

The materials most commonly used for ballast are, 1. Gravel; 2. Bricks, or fragments of old masonry; 3. Vilvoorden stone;* 4. Doornik stone,* of

* These are limestones from Belgium. The last named can be quarried in regular masses, and is used for copings and pillars, or wherever cut-stone masses are required.

which a greater or less quantity is necessary, according to their different specific gravities.

The specific gravity of the osier of Holland, saturated with water, is experimentally determined at 0.628, but a cubic metre of osier-work consists of only 0.295 of wood, the interstices making up the rest. The piece must be loaded until the specific gravity of the composite mass exceeds that of water. The necessary quantity of each kind of ballast can easily be calculated, or the thickness of the layer of ballast for a "*zinkstuk*" of given magnitude. It is usual to allow one-fourth overweight, and still another fourth for the effect ("*werking*") of the currents.

Indeed even this quantity of ballast cannot be considered sufficient, for the currents or waves may sweep away the ballast from a portion of the piece, which should be sufficiently weighted to sink into the depression should the current undermine a portion of its edge. Moreover, all parts should be so covered with gravel and other ballast as to protect it from destruction by the worm.

The mattresses must therefore be ballasted with heavier stone in larger quantities, according as they are more exposed to the action of currents and waves.

The "gangways" are usually filled with Vilvoorden, Doornik, or Norway stone, and advisably with double the quantity, to equal the weight of water for that portion. Over the middle portions gravel and rubbish may be used.

The cost of the "*zink-stukken*" (osier-work alone) is stated at from 1.25 to 2.10 florins (50 to 85 cents about) per square metre, according to thickness varying from $0^{m}.40$ to 1 metre.

For pieces placed below low water, and hence not exposed to violent wave action, $0^{m}.50$ thickness (costing 1.60 florins per square metre) is sufficient.

Ballast: 0.18 cubic metre gravel per square metre; 0.13 "last" of Vilvoorden; 0.114 "last" of Doornik stone per square metre of "gangway;" 0.12 "last"* of rubbish over the whole upper surface; so that, for a piece

* The "last" is about two English tons.

100 metres long and 10 metres broad, and 0m.50 thickness of osier, the cost would amount to—

	Florins.
805 × 0.18 = 144.90 cubic metres gravel, at 1 florin	144.90
195 × 0.114 = 22.23 "last" Doornik stone, at 10 florins	222.30
1,000 × 0.12 = 120 "last" rubbish, at 4.50 florins	540.00
	907.20
To which add the cost of 1,000 square metres of osier-work (cost of sinking included)	1,392.25
	2,299.45

(equal to about $900. The prices above are from the work of Storm-Buijsing, 1854, and have therefore no particular relation to the works here described, prices are now considerably higher.)

The foregoing will, I think, afford a tolerably full understanding of the interesting work which the government of Holland, through the counsels and agency of its "Waterstaat,"* is executing for the improvement of the navigation to Rotterdam. The facts and reasons set forth in the report of the council involve much that is of great interest to engineers. While on the one hand there is shown the greatest caution in attempting to alter existing channels, and reliance is had rather upon bringing natural forces to bear than in applying artificial ones, yet on the other hand the bold step is taken of closing an existing mouth and creating another for one of the great outlets of the combined Rhine and Meuse, and of projecting into the sea, upon a sand shore, entrance jettees reaching to 4½ fathoms (low water) line. In this respect the project seems even bolder than that of the artificial harbor for the North Sea Canal. These jettees differ from those of the last-named harbor in this important particular: they are of fascine-work, and they are, moreover, the *first* constructions of that kind ever attempted upon the open sea-shore. Universal as is this kind of hydraulic construction for the dams

* The "Waterstaat" of Holland is a permanent board, (or corps, perhaps it would be more properly called,) having charge of the national hydraulic works of Holland and supervision over the river and ocean dikes, by which the country is protected from inundation, as well as of the system of drainage. As organized in 1848, it consists of two inspectors, five engineers-in-chief of the first class, four engineers-in-chief of the second class, fifteen engineers of the first and fifteen of the second class. A history and account of the "Waterstaat" and its works will be found in "Engineering," Vol. XII, 1871.

and dikes obstructing or confining internal waters,* no attempt had been made to project a jettee into the sea in this way. The construction of those of the North Sea Canal Harbor has demonstrated triumphantly that artificial jettee construction, with concrete blocks regularly laid, is practicable even upon a sand shore; but the experience by which the knowledge is gained was acquired through frequent failures and much loss of time and money. The history of the jettee construction at the Hook of Holland has been one of complete success. No disaster has occurred, and the completed structure seems to bear the severest storms, the most violent wave-force, undisturbed. The interstices of the fascine-work, as well as those of the stones with which the successive layers are ballasted, become, very speedily, densely packed with sand, which probably extends itself likewise into the spaces between the stones subsequently thrown down as revetment to the sides and base-berms. This sand-filling together with the piles which are driven in the margins and slopes, must be referred to, I presume, to account for the fact that even at the pier-heads the revetting stone (of no great dimensions, as has been seen) are not seriously disturbed by wave-force. To the filling of sand also is due the preservation of the fascine wood from the attack of the worm. The piles, where thus exposed, are covered with worm-nails. All sawed wood-work is coated with tar, and the iron-work is painted while warm, twice with red-lead, and again with black paint.

The two jettees being completed at the time of my visit, so far at least as the laying of the "*zink-stukken*" is concerned, I was not fortunate enough to witness the process; but the details which I have given from Dutch authorities concerning this manner of construction, together with the particular description of the jettees, have sufficed, probably, to make intelligible the process of construction of these jettees.

A ground plan and section of the dam across the old outlet of the Scheur, as actually constructed, are found in Figs. 2 and 3, Pl. IX. The section and dimensions, as originally projected by the commission, are given in page 58. (See Fig. 1, Pl. IX.) In execution, the diagrams just referred to show that the projected form could not be adhered to. The variations are probably due, in part at least, to the manner in which the work was carried

*The great dam across the Y at Schellingwoude is one of the most notable applications.

on. The total width of the Scheur where dammed, measured at water surface, was between 300 and 400 metres. This outlet could not, of course, be stopped until a new channel should be cut through the Hook of Holland. While the latter work was in execution, "cribs" (*kribben*) or jettees, connecting with the shore embankments, were projected from either side, contracting the channel to 130 metres, and confining it to the deepest existing portion. Lest the accelerated tidal currents should abrade the bottom of this opening, a "*bezinking*" (or bottom revetment of fascine-work, with the usual stone ballasting), was sunk, extending from crib to crib. In process of time it was found that the bottom along and contiguous to the edges of this was greatly deepened, undermining the edges and giving a section shown by the lower line of Fig. 3. The difficulty of the subsequent construction of the dam was thereby greatly enhanced, since the regular process of sinking of mattresses could not be applied until the great inequalities of the bottom were levelled by, as I suppose, the application, along the edges and in the deeper portions, of successive small pieces. The dam was completed at the time of my visit. The general method of construction has been already given, and applies equally to the harbor jettees—the great dam at Schellingwoude* and the dam in question.

To the new outlet is to be given, as has been already stated, a width of 800 metres, increasing at the origin of the entrance jettees to 850, and at their outer extremities to 900 metres. The old outlet of the Scheur had about 350 metres width at its surface line, probably not over half that width of deep-water channel. Hence the augmented width of the new entrance implies a greatly increased in and out flow of tidal water. How this is to be attained has been already described. At the time of my visit, early in October, 1871, the channel had been cut through to a width of about 200 metres, and quite recently opened. It was intended to enlarge it gradually to the full projected width. Between the harbor-piers a narrow, somewhat crooked, and not yet navigable channel had formed. By letter of the 30th March, the chief engineer, Mr. P. Caland, informs me that "steam and sail-

* In the Schellingwonde dam, however, the fascine-work or "*zink-stukken*" forms only the bedding course and the side revetments, the interior being filled with sand. That dam is not exposed to violent wave-force, and it is raised entirely above overflow. It does not need piles nor the heavy stone top pavement of the works just described.

ing vessels are actually passing through the new water-way of Rotterdam to the sea, and to all the ports of Europe."

The work is regarded as a complete success.

In conclusion, I remark that Rotterdam, like Amsterdam (the two great sea-ports and commercial cities of Holland), has found her existing communications with the sea insufficient for the demands of her commerce—inadequate to the exigencies of the modern instruments of ocean navigation. Both cities, aided by their government, have had recourse to extraordinary means of regaining their rank among the great sea-ports of the world.

While the principles involved in the very dissimilar projects to which they have had recourse—each shaped and governed by respective local circumstances—are not without applicability to our works of river and harbor improvement, and are certainly of great interest to engineers, it is believed that the peculiar methods of hydraulic engineering of Holland, which have found a novel and heretofore untried application in the forming of a new water-way from Rotterdam to the sea, may be found extremely useful in our own country.

In the construction of harbor jettees, or even breakwaters, upon our extensive sand coasts, the system deserves trial. While, intrinsically, much more economical than constructions wholly of stone,* it is to be observed that, generally, the localities where it is applicable are destitute of that material while they abound in the necessary materials for fascine-work.

In its application to inland waters it seems to me likely to prove especially available in Louisiana. For the damming of deep river arms and the construction of dikes, its efficiency has been proved by the experience of centuries in Holland.†

* I was informed that 100 metres of the jettees of the Hook of Holland cost 136,000 gulden, about $544, per running metre, or $490 per running yard.

† What I have extracted from Caland and Storm-Buijsing, p. 61, applies only or mainly to the use of fascine-work in subaqueous constructions. Concerning its more general and universal use in other positions in Holland, I have not undertaken to write.

APPENDIX I.

The pages which precede the reference are condensed from the report* of the commission, instituted by the government, which resulted in the submission of a project upon which the present works of improvement are based.

I have omitted all that does not apply particularly to the final project and its execution. For a full understanding of the scope of the labors of the commission, I insert here the memorandum of topics submitted by the minister.

"To examine the projects for the improvement of the outlet of Brielle and to give their advice thereon, with proposition of such amendments as will seem desirable.

"To answer the question: Whether it is probable, and to be counted on with any certainty, that the bar (*banken*) in the outlet will increase in depth, and if they adhere to this opinion whether it can be decided how great an augmentation of depth may be anticipated.

"In case, in the opinion of the commission, the proposed improvement of the outlet of Brielle can be recommended, to reply to the question: Whether it will still be advisable to improve immediately the canal of Voorne in order to meet the pressure of the great navigation with America.

"To indicate the character of the improvements which should in that case be applied to the canal of Voorne for the object named.

"To consider if it will be advisable to shut off from the canal of Voorne the drainage of the neighboring "polders," in order to be able to maintain uninterruptedly a raised level in the canal without causing detriment to the lands.

* The title rendered into English is as follows: "Report concerning the improvement of the water communication from Rotterdam to the sea, made by a commission of the 'Waterstaat,' appointed by a decree of the minister of the interior of the 5th of November, 1857." The commission consisted of the following engineers of the "Waterstaat," viz: H. F. Fijnje, president; ——— Conrad; D. J. Storm-Buijsing; J. A. Beijerinck; J. Ortt v. Schonauwen; P. Caland, member and secretary (now chief engineer).

"To state the works which must be made for that purpose.

"To consider whether (observing the conditions of the outlets of Goedereede and Brouwershaven, and without regarding whether the canal of Voorne will or will not be improved ere long) it is to be thought advisable for the government to construct a canal through Goedereede or Overflakkee, having the same dimensions as the canal of Voorne when enlarged.

"In case of an affirmative answer to the last questions, to consider: Whether the shoal of the so-called Pampus, in the track between the canal of Voorne and the canal to be constructed through Goedereede or Overflakkee, is not so objectionable that the experiment of removing this shoal should precede any definite decision to construct such a canal, indicating the means which, in the opinion of the board, would be sufficient to get the required depth over the Pampus.

"To consider the advisability of constructing a harbor of refuge at Brouwershaven entrance, and on which shore, with indication of the principal dimensions which should be given to this harbor.

"To consider whether it is advisable, in the general interests of commerce and navigation, to improve the existing harbor of Brouwershaven, with indication of the manner in which it should be done."

APPENDIX II.

The following is taken from a report by the late Colonel G. W. Hughes to the chief of topographical engineers, dated September 30, 1843:

GREAT CANAL THROUGH THE ISLAND OF VOORNE, IN THE PROVINCE OF SOUTH HOLLAND.

For large merchantmen the navigation from Rotterdam to the sea was attended with many difficulties, arising partly from the strong currents and contrary winds, and partly from the shallowness of water on the bar at the mouth of the Maas, below Brielle. In consequence of which it often became necessary to break bulk and resort to lighters, by which much valuable time was lost, amounting often to several weeks, or else to pursue the southern and circuitous route by the way of Dort and Hellevoetsluis, which offers, at all times, a sufficient depth of water for the very largest ships. For the purpose of avoiding this necessary *detour* a canal has been dug through the isle of Voorne, opening a regular and direct communication between Rotterdam and Hellevoetsluis, through which East Indiamen and first-rate frigates may reach the former port in a single day from the mouth of the Maas.

This canal passes in a straight line through the Isle of Voorne, beginning on the river Maas, between the villages of Heenvliet and Zwartewaal, and ending in the Haringvliet near Hellevoetsluis, where it forms a small angle.

At both the extremities of the canal are sluices or guard-locks, the water in the canal (usual height) being upon a level with low water at Hellevoetsluis or in the Haringvliet, which is 3 feet A. P. These sluices or locks are also provided with contrivances by which the flood-tide may be used in cleaning out the canal.

Both sluices are nearly of the same construction and dimensions; that at the Maas extremity has a drawbridge over it.

Each of the sluices, or rather guard-locks, consists of two separate sluices, having each two flood and two ebb gates, by means of which vessels can always pass, whether the water in the lock be higher or lower than without.

The usual height of the water in the canal is upon a level with the low water at Hellevoetsluis; the whole, however, is so regulated that water may be let into the canal at every flood, and, if required, during the whole of the flood tide.

The difference of the water's height between ebb and flood is 6 feet, and with this difference the usual height of the water in the canal may, every flood, be wholly or partly increased.

In the outer ebb-gates of each sluice are port-holes for the purpose of drawing off the water of the canal when it becomes necessary to diminish its depth.

There are four floating bridges in the canal, so constructed as to allow vessels to pass at any height of the water, and causing no stoppage to carriages.

The dimensions of the canal at its usual height, which is the low-water mark at Hellevoetsluis, are as follows:

Width of the sluices	45 feet 6 inches.
Depth on the gate-sills at low water	17 feet 3 inches.
Each guard-lock sluice (as before stated) consists of two sluices, each of which are in length (for the whole lock)	106 feet.
The inner and outer single sluices are at a distance from each other of.	130 feet.
The lock between the gates	236 feet.
The floating bridges open	48 feet.
The depth of the canal below low water	16 feet 4 inches.
Breadth at the bottom	35 feet 9 inches.
Breadth at the surface (low water's depth)	110 feet 6 inches.

The whole length of the canal, which has dikes on both sides, is about six miles (English).

The canal is provided with a towing-path on each side 13 feet wide, for the purpose of tracking vessels through the canal.

The surplus waters of the adjacent lands are drawn off through four

self-acting sluice-gates of 10-feet openings, fitted up with *vanne* gates, which close spontaneously when the water of the canal is at a higher level than the ditches. Water-wiers have also been constructed through the lateral dikes, for the purpose of irrigating the meadows in seasons of protracted drought.

This work was begun in the year 1827 and finished in 1830.

APPENDIX III.

The following account of the works at Katwijk is from the same source as Appendix II:

The Rhine, after descending into Holland, throws off various branches to seek the ocean, as the Waal, the Linghe, the Leck, the Issel, &c., many of them important rivers, while the most insignificant of them all is the only one retaining the original and time-honored name. It passes through Leyden—the *Lugdunum Batavorum* of the Romans—and is discharged into the German Sea at Katwijk about seven miles from that town. The debouche of the Rhine on the coast was so blocked up by a barrier of drifted sand thrown up by a violent tempest in 840 that the waters could only filter their way to the sea, and all navigation was of course stopped. The consequence was that a large district of country was overflowed and converted into a sickly marsh. For the purpose of opening a new channel to discharge the waters of the river and for the better drainage of the low grounds called Rynland, the canal of Katwijk was constructed—a work, although of short extent, that may, from the boldness of its design, the success of its execution, and the difficulties encountered, be ranked among the grandest and most important of the hydraulic structures of which Holland is so justly proud.

The first *projet* for this canal was suggested in 1404, but it was not till 1571 that a serious attempt was made to carry it into execution; but when commenced it was prosecuted with so much vigor that on the 1st of April of the following year, the last coffer-dam having been cut and the sluices opened (in the presence of the authorities and an immense crowd of bystanders), the interior waters, which had been so long pent up, were seen to rush violently into the German Ocean. In consequence, however, of the civil

troubles and the foreign wars, the canal was interrupted before it had been entirely completed, and again disappeared beneath the drifting sands, where it remained buried till the year 1802, about which time this project was again agitated, and the execution of it finally ordered by the legislature of the Batavian Republic in the month of May, 1804. The works, begun in August, 1804, were finished in 1807, under the superintendence of Mr. Conrad, a distinguished French engineer.

The canal is about 4 miles long, 49 feet wide at bottom, 52 feet at surface, and 6 feet 3 inches in depth* (mean). The water is withheld by means of an inner and an outer flood-gate and a sluice-bridge. The outer flood-gate, on the sea-shore, has 5 sluices of 12 feet 6 inches opening each, presenting thus to the flowing of the water a thoroughfare of 62 feet 6 inches. The length of the aperture walls, measured on the middle line, is 63 feet 5 inches. The sluice-floors are 17 feet 3 inches below the highest tides.

Each sluice is provided with a pair of tide-gates, a strong flood-gate, and a turning door (*porte tournante*) for cleaning the sluice.

The tide-gates (*portes de flot*) are not as high as the highest tides, but rest against a staying girder, above which the water is restrained by a heavy arch of brick-work, against which the most furious tempests have beaten without effect.

At 1,462 feet 6 inches back from the first flood-gate is the second flood-gate, just within the dunes. This flood-gate has three sluices, each of 18 feet opening, making in all a total width of 54 feet. The length of aperture walls is 96 feet. The sluice-floors are 17 feet 3 inches below the highest tides.

A sluice-bridge (*port éclusé*), provided with three sluices of 20-foot openings, arranged with floating doors (*portes flottantes*), can, if necessary, be used as a third withholder during extraordinary high tides.

The junction of the terminus of this work with the sea has been effected by means of jettees formed of fascines (secured in position by piles driven into the sands), on which heavy masonry has been laid. The fascines prevent the underwash; and the masonry, formed of huge stones, or rather

*Since the commencement of the drainage of the Lake of Haarlem the dimensions of the canal have been greatly increased.

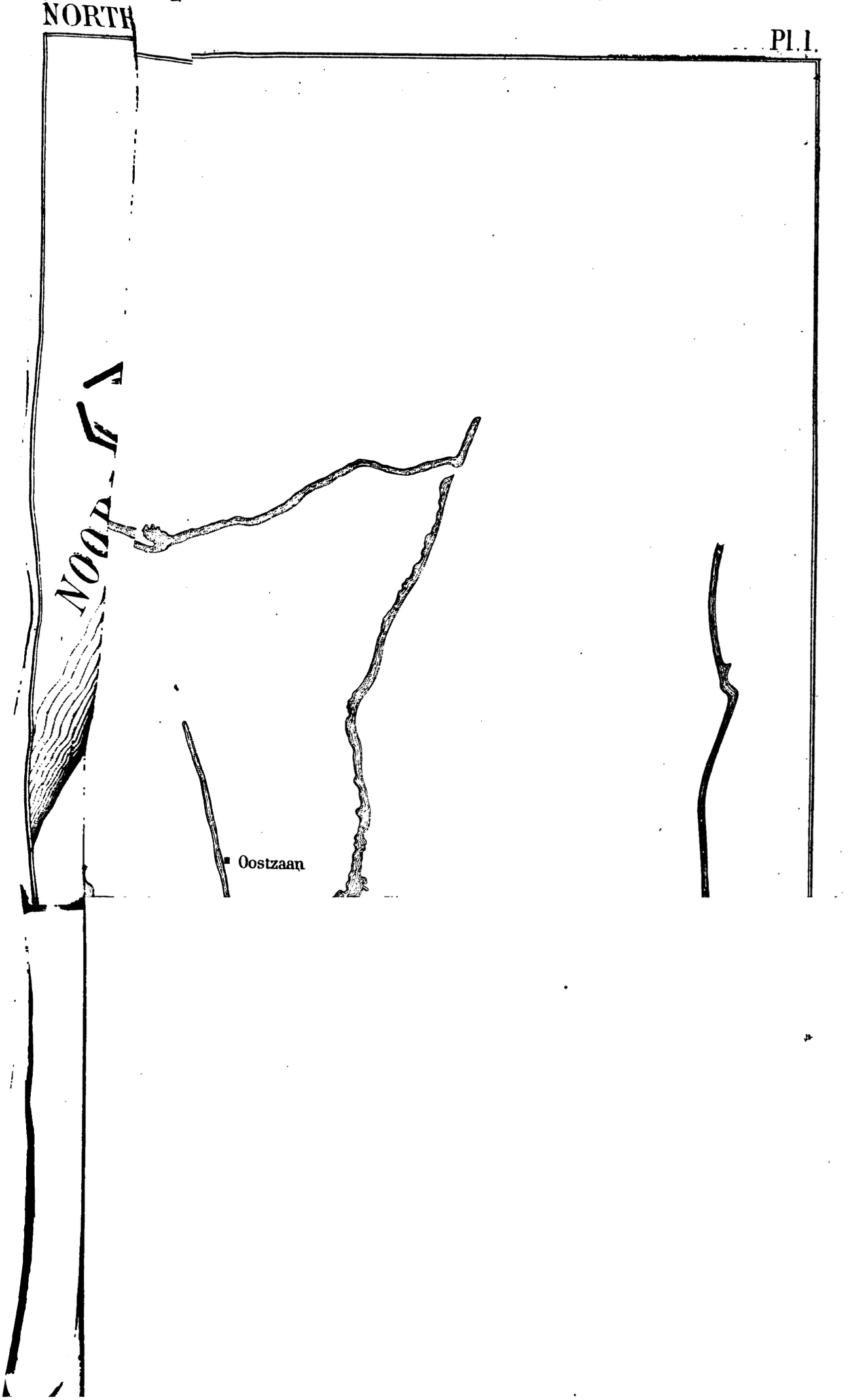
rocks, is sufficiently strong to resist the force of the waves. These piers are 625 feet long, leaving between them a basin 320 feet wide.

The difference in level between the inner water and the ebb-tide being usually only about 16 inches, it was feared in the beginning of the undertaking that the outer channel would be liable to fill up with sand; to prevent which, by creating a greater scour, a steam-engine was established with the view of raising the water within the gates to a level higher than its natural one.

Time, however, having shown that the flowing out of the water at low tide was sufficient to keep the basin free from the accretion of shingle, the engine was sold many years ago.

When the flood-tide commences, the gates of which we have spoken are closed, to prevent the entrance of the sea. At extraordinary high tides the exterior water rises about 17 feet, pressing against the gates, and is several feet above the inner waters.

When the tide is on the ebb the gates are opened by means of machinery, and the accumulated waters, which had been withheld during the flood, are allowed to flow out, carrying with them the sand which may have been brought in by the rising tides. The water discharged by the sluices has been estimated at 100,000 cubic feet per second; but when strong western winds prevail, and the tides do not subside to their ordinary level, it is impossible to open the gates, and no discharge can take place.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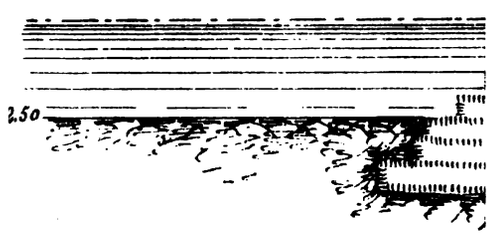

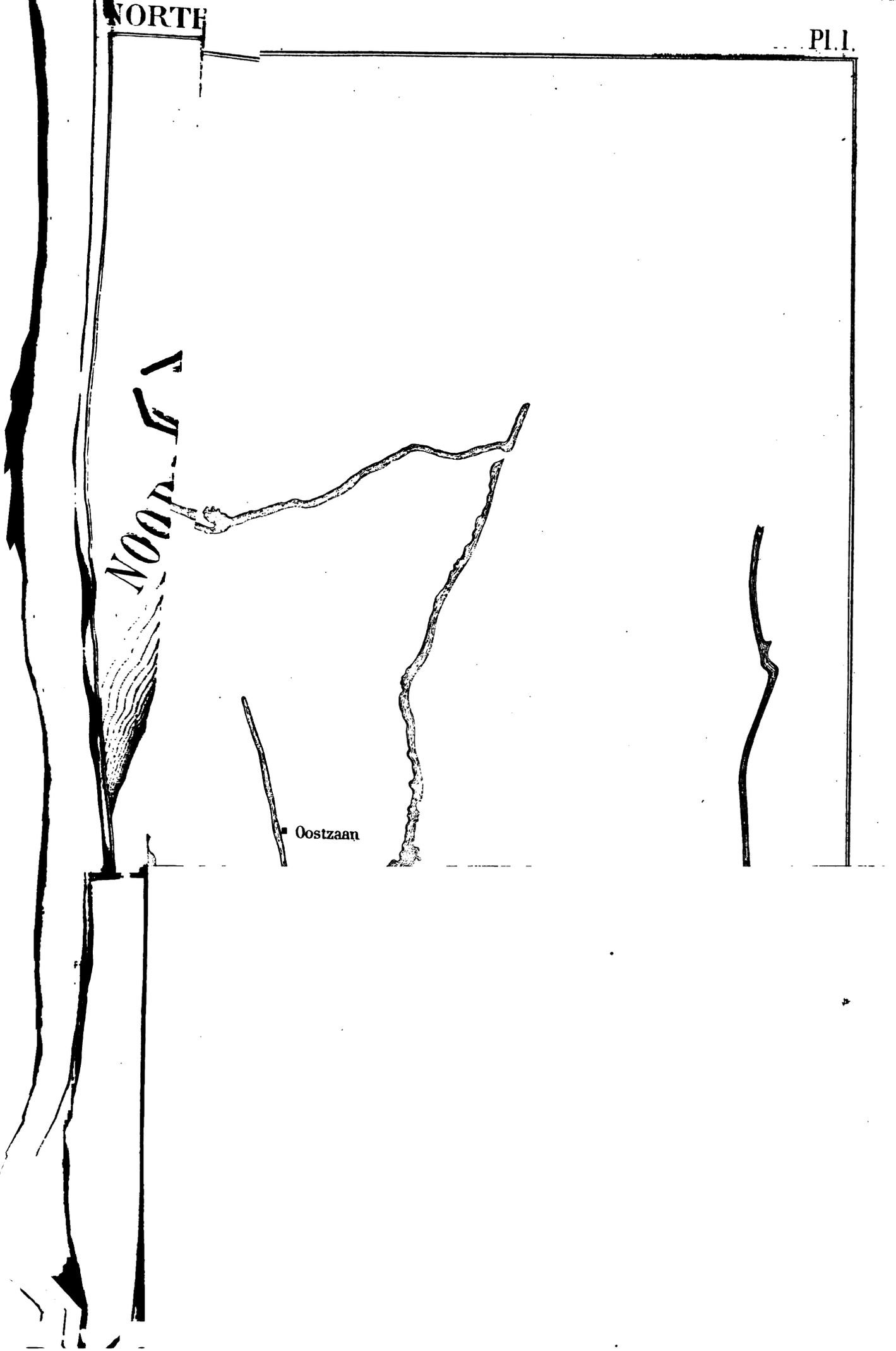
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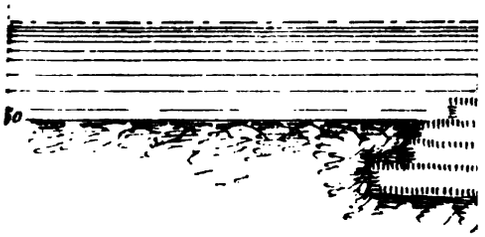

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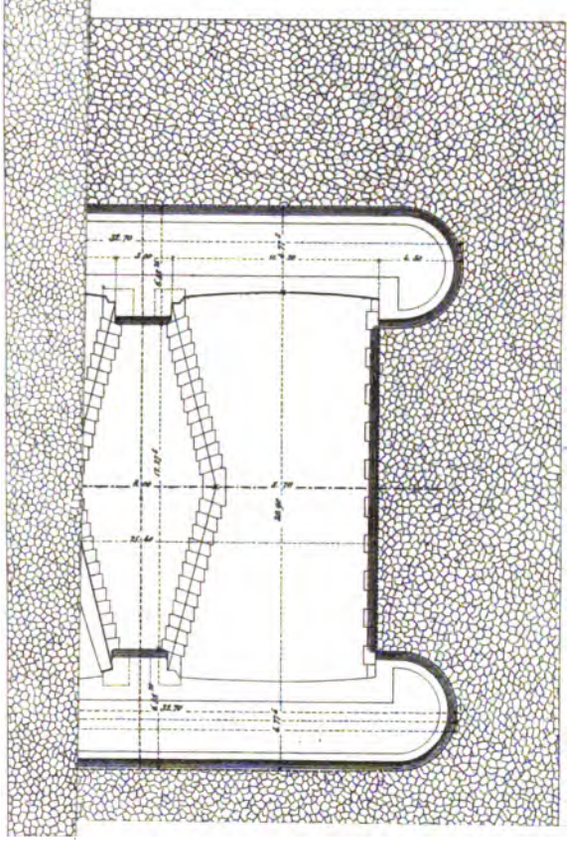

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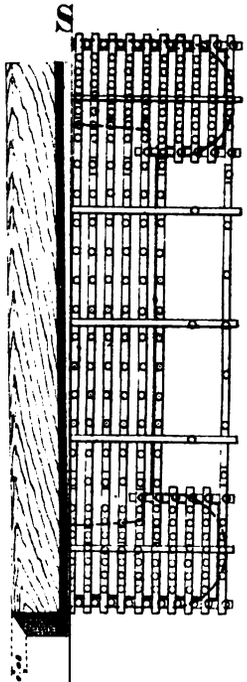

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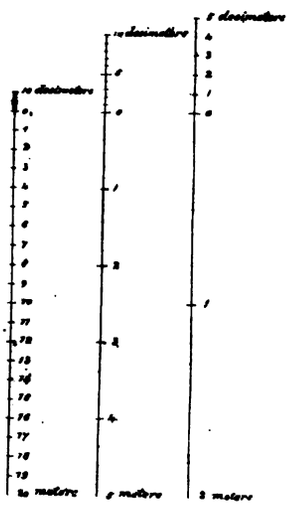

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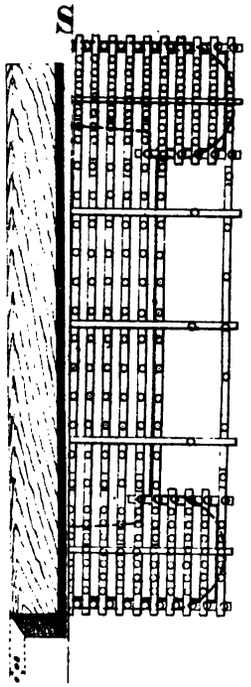

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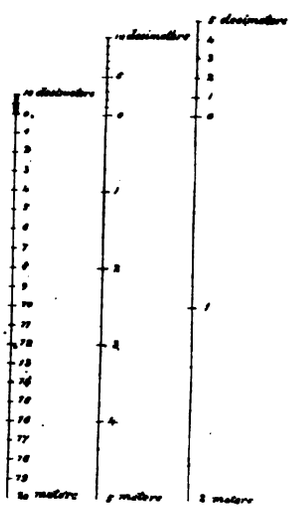

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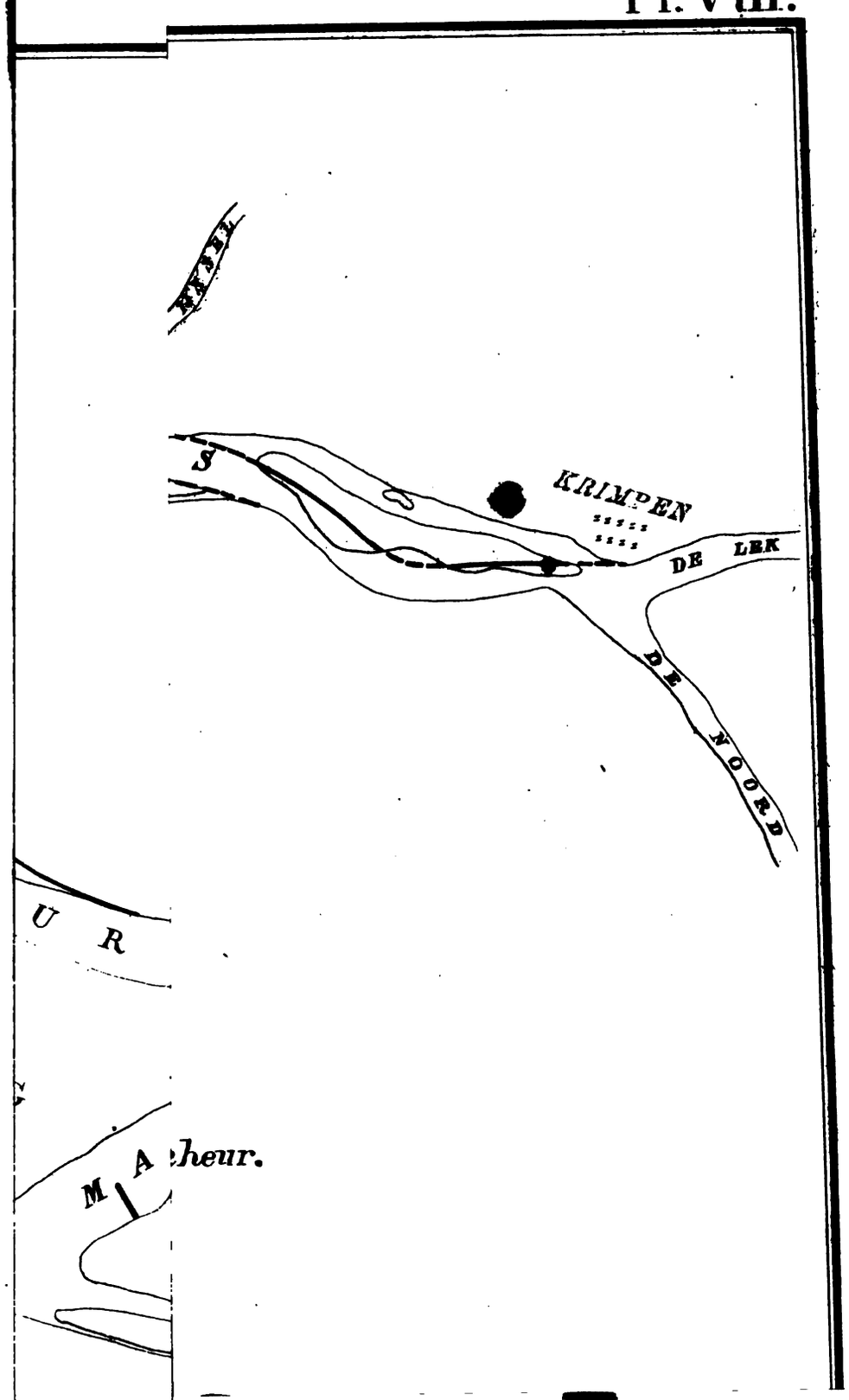

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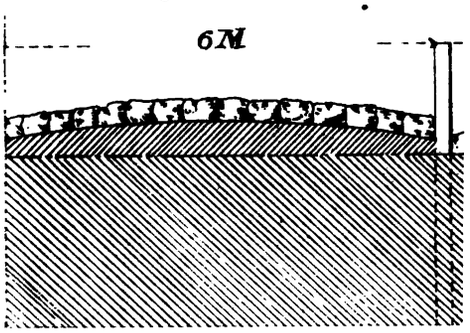

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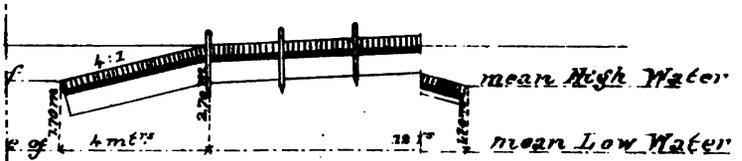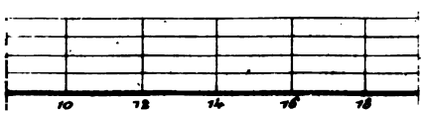

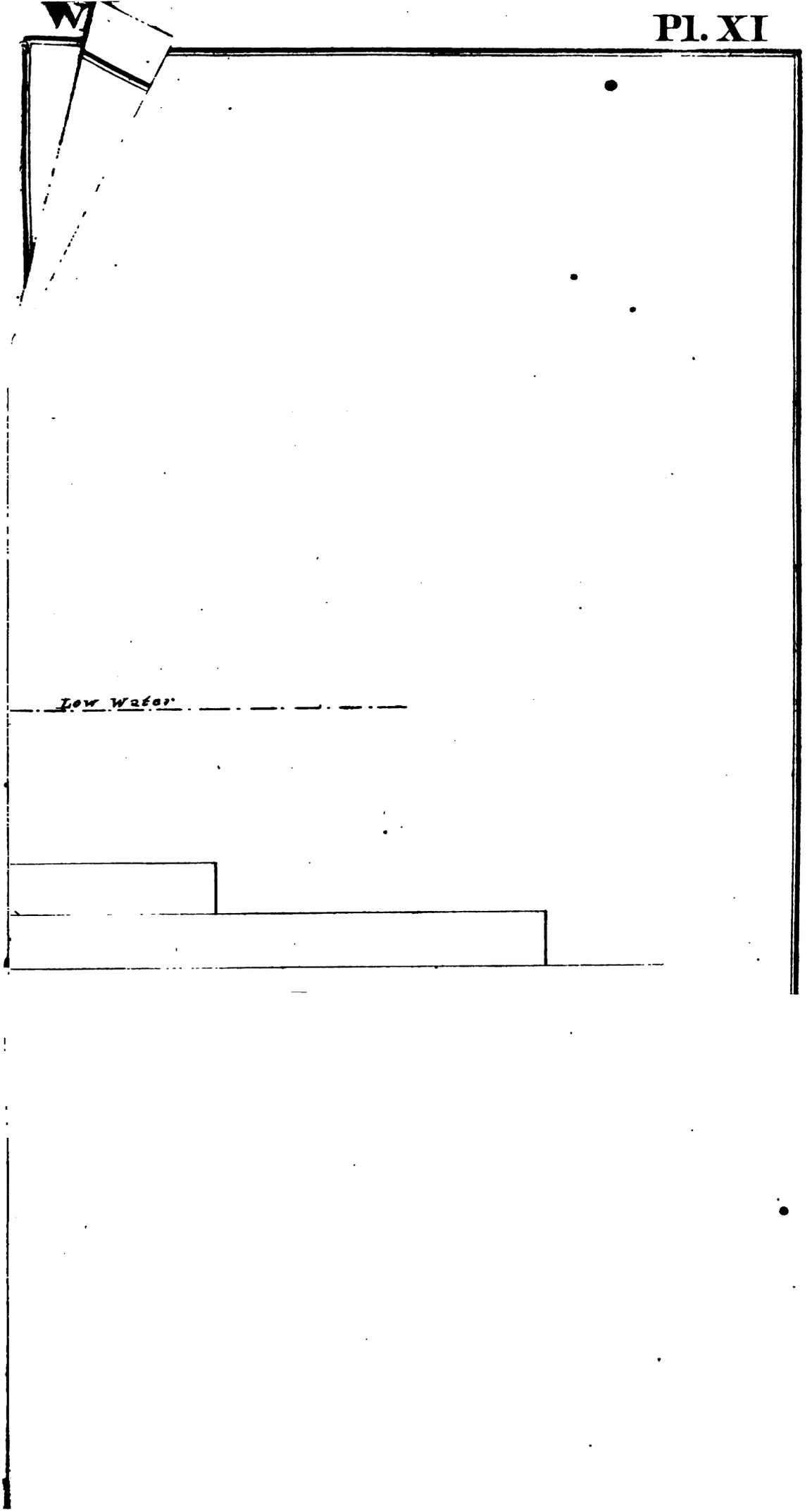
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